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New Trends in Fibers Used in Denim Fabric Production

Denim Kumaş Üretiminde Kullanılan Liflerde Yeni Trendler

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Derleme Makale/ Review Article

NEW TRENDS IN FIBERS USED IN DENIM FABRIC PRODUCTION

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ABSTRACT: There is a tendency to use different fibers from cotton to improve the physical properties of conventional denim fabrics, add functional properties, and follow trends and fashion. Warp and weft yarns can be produced with 100% cotton or composed of different fibers optionally for denim fabric. In this study, a piece of detailed information was given about the fibers used for denim fabrics in recent years, and the effects of the fibers were evaluated. In the results of the review, the nature of the fiber and antibacterial property is the most prominent feature nowadays for cellulosic fibers. It is quite advantageous antibacterial fibers also have additional functional properties without further processing. Wool and silk are widely used in conventional textile. They are especially preferred when thermal comfort is required in denim fabric production. Synthetic fibers are indispensable for denim especially when high performance is needed. Also, it is important for the wearer to feel comfortable, so new generations of synthetic fibers that provide high comfort are widely used. Elastane is a characteristic fiber of denim fabric and always a new type of elastane fiber is produced. Besides elastane used in flexible denim fabrics, elastomultiester fibers are popular now. These fibers do not contain elastane but they provide excellent elasticity and recovery for the fabric.

Keywords: Denim, Functional Denim, New Fiber, Trend Fiber.

DENİM KUMAŞ ÜRETİMİNDE KULLANILAN LİFLERDE YENİ TRENDLER

ÖZET: Geleneksel denim kumaşların fiziksel özelliklerini iyileştirmek, yeni fonksiyonel özellikler eklemek, trend ve modayı yakından takip etmek için pamuğun yanı sıra farklı lifler de tercih edilmektedir. Denim kumaşlarda çözgü ve atkı iplikleri tercihe bağlı olarak % 100 pamuktan üretilebildiği gibi, farklı lif kompozisyonları da kullanılmaktadır. Bu çalışmada, son yıllarda denim kumaşlarda kullanılan lifler hakkında detaylı bilgi verilmiş ve liflerin denim kumaşa etkileri değerlendirilmiştir. Buna göre, selüloz esaslı lifler için doğallık ve antibakteriyellik ön planda olan özelliklerdir. Bu liflerin sahip olduğu fonksiyonel özellikler, üretim sırasında ilave işlemlere gerek kalmamasından dolayı büyük bir avantaj kazandırmaktadır. Yün ve ipek, geleneksel tekstil üretiminde yaygın olarak kullanılmakla birlikte denim kumaş üretiminde, özellikle termal konfor gerektiğinde tercih edilmektedirler. Sentetik lifler, yüksek performanslı denim kumaş üretimi için vazgeçilmezdir. Ek olarak, kullanıcının rahat hissetmesi önemli olduğundan yüksek konforlu yeni nesil sentetik lifler yaygın olarak kullanılmaktadır. Elastan, denim kumaşların karakteristik lifidir ve elastan liflerine her geçen gün bir yenisi eklenmektedir. Esnek denim kumaşlarda kullanılan elastan liflerinin yanı sıra, elastomultiester lifler de ilgi çekicidir. Bu lifler elastan içermemelerine rağmen, denim kumaşlara mükemmel esneklik kazandırmaktadırlar.

Anahtar Kelimeler: Denim, Fonksiyonel Denim, Trend Lif, Yeni Lif.

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1. INTRODUCTION

Denim fabric is in high demand in the textile market, and this is increasing day by day. Denim fabric is not only used for jeans production but also for textile products such as shirts, t-shirts, skirts, and coats according to daily fashion trends. Denim fabrics should have different performance and functional properties, depending on the purpose of use. It is necessary to design fabrics in different constructions to make suitable raw material/fiber selection, to use specially produced yarns, or to apply functional finishing processes to improve fabric properties. Washing and finishing processes on denim fabrics provide a better attitude and appearance and increase the attractiveness of denim. One way to improve the mechanical performance of denim fabrics is to choose fibers and yarns that have different properties [1]. However, different cellulosic, protein, and synthetic-based fibers are used in the production of denim fabrics today. These fibers often change the usage performance properties of denim fabric, as well as they are also preferred to follow changes in trends and to be different from the others. The type and characteristics of fiber are very important because they directly affect the technology of denim fabric.

2. TRENDS IN CELLULOSIC FIBERS USED IN DENIM FABRIC PRODUCTION

2.1. Regenerated Cellulose Fibers

Cotton is still the most preferred fiber type in denim fabrics. But fibers which are widely used in textiles or that are obtained with new technologies are also used in denim production either alone or blended with cotton. Cellulosic-based Modal® fiber, which is developed by Lenzing, is generally used in underwear because it prevents sweating. It is also popular in denim because it provides a silky appearance and soft touch. Modal® has 50% higher moisture absorbance than cotton [2, 3]. Modal® Black fibers have been used in denim production due to demand for black colored and non-fading denim fabrics. Colors of Modal® Black garments are more permanent, unlike other textiles that are discolored as they are washed. Because pigments penetrate fiber during the dope dyeing technique. Therefore, color does not fade even after 50 washes. A small amount of dye (80%) is required for producing Lenzing Modal® Black compared to other dyeing techniques. Also, researches show less water and energy are used during fabric production with Lenzing Modal® Black fibers so that the carbon footprint of the product is low [4]. Tencel™ (Lyocell) fibers are obtained from the pulp cellulose of trees such as birch, oak, or eucalyptus by the wet or dry spinning method. They are breathable with their nature and comfortable due to the transfer of moisture. Soft, bright, antiperspirant, and high strength denim clothes are obtained when Tencel™ fibers are used [5]. Kumari ve Khurana (2016), investigated the comfort properties of denim fabrics containing Modal®, Tencel™, and bamboo. The results showed fibers differ with raw material and production techniques but this didn't make any significant difference in the final product. Cellulose content in fibers determined % moisture content that gives the human body a cool feeling. Users feel more comfortable as yarn fineness and hairiness decrease and softness increases. [6].

Bamboo fibers are environmentally friendly because bamboo production methods do not harm the environment and human health. Bamboo fiber has a high moisture absorption capacity, allows evaporation of moisture rapidly. Functional properties, which originate from the nature of bamboo, increase the advantages and usage of fibers [7]. The cross-sectional view of the bamboo fiber is shown in Fig. 1.

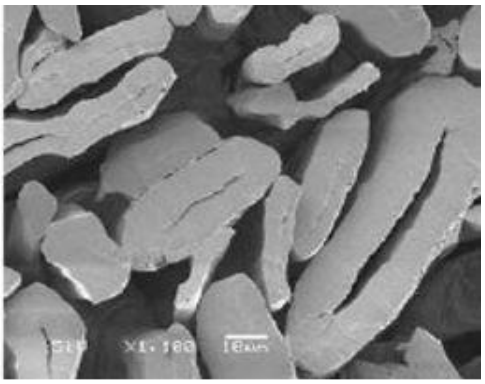


Fig. 1 Cross-section of bamboo fiber [2]

There are hollow structures in the cross-section of the bamboo fiber as seen above. Bamboo fiber quickly absorbs moisture and transfers it through this hollow structure. Compared to cotton, the physical properties are slightly better. Amorphous sections are more than cotton and viscose [8]. Bamboo fiber has a natural antibacterial feature and the antibacterial property of fabric increases as the amount of bamboo increases. Bamboo fiber should not be used less than 70% for a satisfactory level of antibacterial activity [2]. Changjian et al. (2005), studied bamboo and cotton blended elastic jeans [9]. Zhu and Cui (2005), developed elastic denim fabric using bamboo and elastane. After sandblasting and washing processes, it was observed that the strength and shrinkage values of bamboo denim showed similar results to cotton, but bamboo denim was softer [10]. Sheng (2010), studied the use of bamboo/poly trimethylene terephthalate (PTT)/cotton blended yarns in jeans, and also examined the parameters affecting the process. This newly developed denim fabric had high air, and moisture permeability, elastic structure, antibacterial property and soft-touch [11]. Rathod and Kalhatkar (2013), examined the physical properties of different denim fabrics produced from cotton and bamboo/polyester blended yarns with different numbers. 100% cotton and 75:25 bamboo/polyester blended yarns were used for denim fabrics. Bamboo/ polyester blended yarns were found to be more durable but hairier than cotton yarn for all numbers. The tensile strength of bamboo/polyester fabrics was also higher than cotton fabrics. Tear strength was excellent for all fabrics [12]. Nagarajan et al. (2019), produced denim fabrics using bamboo/cotton yarns in warp and weft. The yarn compositions were 100% bamboo, 100% cotton, and bamboo/cotton blends as 70:30, 50:50, and 30:70. Yarns were produced using ring and rotor spinning methods. The most suitable blend ratios were found to be 100% bamboo and 70:30 bamboo/cotton blends [13].

2.2. Kapok Fibers

Kapok is a cellulose-based fiber that is more hygroscopic and keeps warmer than cotton because of a 90% hollow degree in its structure [14]. Kapok also has a good natural antibacterial property. Kapok fiber has superior properties and is more economical than cotton, and this is of interest to denim manufacturer who wants to produce high-tech products, especially in China. Therefore, kapok fiber has high market competitiveness. Wei et al. (2016), studied on bleaching of kapok/cotton denim with a carbon dioxide laser and compared the results with cotton and polyethylene terephthalate (PET) denim fabrics. The colors of the fabrics faded and their K/S values decreased after laser bleaching. As the intensity of the applied laser increased, and the application speed decreased, K/S values and strength of fabrics decreased significantly. The results showed that laser bleaching is suitable for kapok denim fabrics [15]. Wei et al., (2019) bleached denim fabrics using cellulase, sodium hypochlorite, potassium permanganate, hydrogen peroxide, and laser. K/S values of denim fabrics decreased after all bleaching processes, and especially, the strength and weight of fabrics decreased when used potassium permanganate. The rubbing fastness and crease recovery angle values of the laser-treated denim fabrics were suitable for the industry [14].

2.3. Peppermint Fibers

Peppermint fiber, a natural, biodegradable, and cellulose-based fiber, is antibacterial and has a natural cooling effect. These fibers are fine, such as silk. Therefore, they are more suitable for mixing with other fibers since they are not very crimped. Although they are produced from mint, they do not have any mint smell. If they will be used in the manufacture of garments such as socks and sweaters, it is recommended to use them with wool [16]. Baohua et al. (2013), used cotton, modal, and mint fibers to produce a denim fabric that provides human physiological comfort with an antibacterial feel and gives a feeling of coolness and freshness [17].

2.4. Nettle Fibers

Nettle fiber is one of the important cellulosic fibers. This plant contains fibers similar to bast fibers such as linen and hemp. These fibers are thin, long, and strong, as well as anti-static and antibacterial. Nettle fibers have superior moisture absorption and breathable, so fabric produced with these fibers is very comfortable. They are also sustainable and environmentally friendly, similar to other natural fibers. In recent studies, it is stated that nettle fibers can be used instead of cotton fibers. Fabrics made of nettle fibers are used in clothing, denim, and home textiles due to their high moisture absorption ability and comfort [18, 19, 20, 21]. Fig. 2, shows the jeans produced from nettle fiber.

Nettle fibers are often mixed with cotton, linen, viscose, silk, and bamboo fibers to produce fabrics and these fabrics are now available from numerous companies around the world. Especially in Italian fashion, denim fabrics produced from 10% nettle and 90% cotton attract attention. Nettle fibers are becoming common in denim pants and these fibers are promising [23]. Lee (2018), used nettle fibers as a sustainable material for denim manufacturing and investigated changes in the appearance, and formation of textiles, and proposed nettle fibers as source material for denim fabric. The effects of washing on denim fabric properties were also researched in the study. It was found that the geometric roughness, which is the problematic feature of bast-fiber-like nettle fiber, was reduced by washing [24].

Fig. 2 Denim trousers produced from nettle fibers [22]

2.5. Jute Fibers

Jute fiber is a bast fiber obtained from the bark of the jute plant. It is generally not preferred to produce garments made of jute fibers due to the rough structure, poor washing, and abrasion properties [25, 26]. Ullah et al. (2016), worked to characterize jute-cotton blended fabric. In their study, they produced 50:50 and 30:70 ratio of jute-cotton blended fabrics with 2/1 and 3/1 twill structures, respectively. Then, the physical characteristics and color values of the fabric were examined. As a result, it was stated that the use of fabrics made from jute-cotton blended yarns will increase the added value and improve the economy since locally produced jute fibers are cheaper than cotton [25]. Elahi et al. (2019), studied the effects of industrial stone-enzyme washing on cotton-jute (75:25) blended denim fabric with 3/1 twill weaving structure. The warp strength was slightly reduced after washing; weft strength increased [27]. Khan et al. (2020), applied chitosan (0% to 1.2%) to jute/cotton blended denim fabrics to improve their antibacterial properties. Denim fabrics were tested against *S. Aureus* and *E.Coli* bacteria and test results showed the antibacterial properties of denim fabrics were improved [28].

2.6. Linen Fibers

Linen is cellulosic based bast fiber. Lu et al. (2004), produced denim fabric using linen and applied appropriate finishing processes to the fabrics. At the end of the study, they developed soft and comfortable denim fabrics [29]. Bihong (2004), stated that linen/cotton denim fabric is absorbent, highly air-permeable, antibacterial, anti-odor, and UV-proof, so it has the great market potential [30]. Chun et al. (2009), measured the antibacterial degree of linen/cotton denim fabrics using AATCC Test Method 100-1999 and stated that the addition of linen to fabric did not show any significant antibacterial activity [31]. Chun et al. (2010), in another study, examined the contribution of the linen content in denim fabric to the antibacterial property. However, although it has been assumed for a long time that linen adds antibacterial

properties to the fabric, they stated that the increase in the content of linen did not contribute to the antibacterial activity [32].

2.7. Hemp Fibers

Although the only cotton is used as a raw material in traditional denim fabrics, adding hemp fiber increases the denim fabric quality. Hemp fiber is suitable for yarn production by mixing with cotton, wool, and silk. The properties of hemp are similar to linen [33]. Denim fabric made from hemp fibers is given in Fig. 3.

Fig. 3 Denim jeans produced from hemp fiber [34]

Huang (2005), worked about hemp denim fabrics and fabrics produced had high air and moisture permeability, UV resistance, comfort, and crispy handle [35].

2.8. Pineapple Leaf Fibers

Pineapple leaf fibers are a natural type of fiber obtained from pineapple leaves. These fibers, which have a very high cellulose ratio, are characterized as a good textile material with their superior mechanical properties and ability to absorb water. Moreover, pineapple leaf fibers have become an important source of raw materials with their easily accessible, biodegradable, and recyclable properties. Fabrics made of pineapple leaf yarns have generally high air and water permeability. The appearance of the fabrics is similar to linen or ramie, but the handle is harder. So, pineapple leaf fibers are used as a mixture instead of using alone, especially in clothing fabrics. It is stated that fabric with polyester and pineapple yarns is soft but its abrasion resistance is low [36].

3. TRENDS IN PROTEIN FIBERS USED IN DENIM FABRIC PRODUCTION

3.1. Wool Fibers

In the early days, denim fabrics were made of wool, but over time trend is for cotton [37]. Jiang et al. (2004), studied denim fabrics consisting of cotton warp and wool weft. Woolen and 100% cotton denim were also compared regarding wearability. As a result of the study, woolen fabrics were new generation denim which was advantageous due to its hygroscopic and porous structure, soft feeling, and excellent resilience properties [38]. Wei (2005), studied designing comfortable and soft fabrics by combining superior properties of worsted wool and cotton [39]. Zhao and Sui (2013), examined properties of denim fabrics produced from combed cotton and worsted wool as warp and weft, respectively. After standard finishing processes soft, breathable, and smooth fabrics were obtained. Wool blended denim fabrics also had good fastness properties, high dimensional stability, and a high market volume [40]. Nawaz et al. (2016), compared the comfort properties of cotton/wool blend and 100% cotton denim fabrics under simulated cold weather conditions. The results showed cotton/wool denim jeans with 66:34 and 83:17 blend ratios had higher thermal comfort than 100% cotton ones for 17˚C. Also, wool blended denim had higher vapor permeability, which was due to the better moisture transfer properties of wool [41]. Woolmark Company used wool fiber as weft and cotton as warp in traditional denim and integrated the advantages of wool into denim fabrics without compromising style [42].

3.2. Silk Fibers

Silk regulates body temperature, provides comfortable use in all weather conditions, and has higher tensile strength than cotton. It prevents odor formation by preventing bacterial growth [43]. Silk fibers have great advantages for denim fabrics and can be woven in various weights. Denim garment produced from silk is appropriate for every season and soft and has a smooth feel, so it is suitable for the dynamism of daily life. Denim fabrics produced from eri silk is equivalent to 100% wool ones regarding thermal properties. When silk fibers are mixed with cotton or linen, the advantages of silk fibers come to the forefront and the fabrics become more economical. Silk blended or 100% silk fabrics bring innovation to the denim market [44].

3.3. Soy Protein Fibers

Soy protein fibers (SPF) are protein-based vegetable fiber. The most important features are soft, bright, smooth, draped, and biodegradable. It is also resistant to UV rays and has antibacterial properties. SPF fibers are used in the production of knitted, woven, nonwoven, and denim fabrics. The commercial name of SPF fibers is Silkool. The colour of fibers may be white or light yellow. Their wet strength is low, and elongation ability is around 40% when dry, and 60% when wet. The moisture absorption properties are between 10-13%. They are similar to other protein fibers regarding chemical properties. It is suitable for use with natural as well as synthetic fibers [45]. Fig. 4 shows the images of soybean fibers.

Although natural protein fibers such as wool and silk have good physical properties and are widely used in the textile industry, they are expensive fibers. But soy protein fibers are cheap and abundant. Thus, it is defined as a fiber to be used as an alternative to wool and cashmere fibers. SPF is used in a mixture with fibers such as cashmere, wool, silk, cotton, and zein. Polyvinyl alcohol (PVA) is used during fiber production to improve the strength of soybean fibers [48, 49].

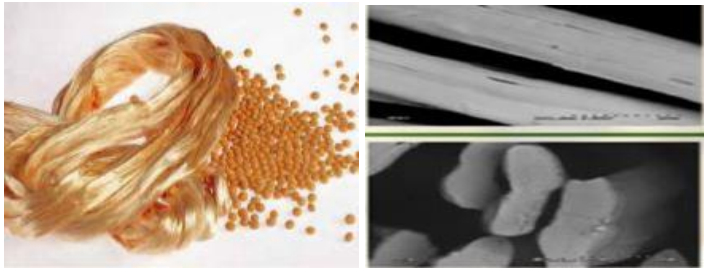


Fig. 4 Soybean protein fibers [46, 47]

3.4. Corn Fibers

Corn fiber is a natural fiber produced by polylactic acid which is fermented from corn amylum. Although their general properties are similar to polyester; they are as bright as silk. Their flexibility and strength properties are good, biodegradable and they have low flammability and smoke generation. They are stiff, rigid, and fragile. Some manufacturers around the world have already started adding corn fibers to clothing. In addition to many clothing products, corn fibers are used in sportswear, jean production, and home textiles [50].

3.5. Cashmere Fibers

Cashmere fiber is produced from goat hair and classified as valuable and luxurious fiber. Even the use of 2.5% in the soft degree of the fabric significantly increases [51]. Liu (2007) studied soften the cashmere/cotton denim fabric by using silicon, and it was observed that the finishing process made with silicon improved the softness and crease-resistant properties of the fabric [52].

4. TRENDS IN SYNTHETIC FIBERS USED IN DENIM FABRIC PRODUCTION

4.1. Polyester Fibers

4.1.1. Coolmax® Fibers

Sweat or moisture should be evaporated from the skin to ensure thermal comfort in routine activities. In polyester-based Coolmax® fibers, the cross-sectional shape is a characteristic tetra-channeled or Hexa-channeled. The surface area is 20% higher than the yarn of the same linear density. The capillary properties of the fiber can absorb moisture from the skin, and spread across the width of the fabric to quickly evaporate the absorbed moisture. Due to the rapid evaporation of sweat, the bodies remain dry and cool [53]. Fig. 5 shows a cross-sectional view of the Coolmax® fibers.

Cross section of the Coolmax® fiber is not round and fiber has four or six channels in the longitudinal direction, and it is slightly rectangular. These channels absorb and evaporate sweat quickly [54]. Jeans, jackets, and shirt denim fabrics with Coolmax® technology are easy-care fabrics that remove moisture from the body to keep the wearer cool and dry. They are also versatile and comfortable. Denim with patented Coolmax® Natural Touch ™ technology provides efficient moisture management, smooth stretch-elongation, a natural look, and ease of use [55]. He et al. (2011), used Coolmax® fiber in the weft yarn of denim-like fabrics. The effects of alkali treatment time on fabric morphology, tensile strength, thermal properties, moisture permeability, dyeing, and fast-drying properties were discussed and weft yarns were compared with polyester ones. The results showed that alkaline treatment increases the absorbing capacity of the fabrics and provides darker dyeing. Also, the optimum alkali treatment time was between 35-60 minutes. The fixing temperature of the fabric containing Coolmax® was 10°C lower than that of conventional denim-like polyester fabric [56]. Coolmax® is high-performance polyester fiber, and for this reason, it has been preferred more recently in the production of denim fabrics. It dries very quickly, and evaporates easily, and keeps the wearer cool through its breathability [57].

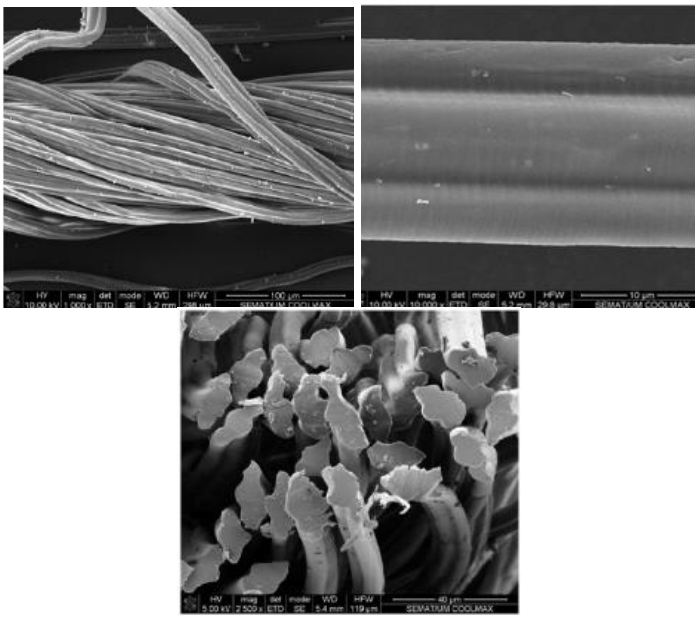


Fig. 5 Cross-section of the Coolmax® fibers [54]

4.1.2. Thermolite® Fibers

Consumers now want to prefer denim garments that keep pace with active lifestyles. Denim fabrics made with Thermolite® brand technologies are designed to keep the user warm in cold conditions without add not bulk to fiber. The insulation properties of denim fabrics produced with Thermolite® Dual Layer technology have improved, and the insulation value (CLO) is 25-30% higher than standard denim fabrics. Besides, it dries quickly, and keeps the skin drier, and makes it feel warm. In the Thermolite® Infrared technology, the yarns increase the temperature of the garment by absorbing the infrared rays, trapping the air through thermal insulation, and minimizing heat loss [58]. Fig. 6 shows a cross-sectional view of Thermolite® fibers.

Fig. 6 Cross-sectional views of Thermolite® fibers [54]

Thermolite® fibers are produced with inspiration from polar bear fur. As can be seen in Fig. 7, cross-section of the fiber is hollow, which makes it is possible to maintain a proper temperature even at the lowest weights. They are also high-performance fibers regarding abrasion resistance [59].

4.2. Polyamide Fibers

4.2.1. Cordura® Fibers

Invista's Cordura® team combines the strength and durability of nylon with the comfort of cotton. Cordura® denim fabrics launched in 2010 consist of blends of cotton and Invista's T420 Nylon 6.6 fibers. Cordura® denim fabric gives exceptional durability, tear and abrasion resistance, and the authentic look and feel like 100% cotton denim. Cordura® jeans have four times more wear resistance than 100% cotton ones, longer life, and high-performance [60, 61]. The structure of Cordura® denim fabrics is given in Fig. 7.

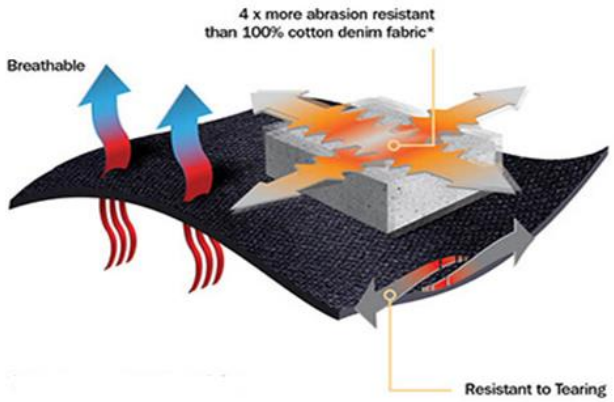


Fig. 7 The structure of Cordura® denim fabrics [61]

In addition to the high-performance properties of denim fabrics produced with Cordura®, the color performance is good as it does not fade for a long time. Kara and Akgün evaluated the effects of different weft yarns such as cotton, Coolmax®, Cordura®, Thermocool® and elastane and fabric structural parameters on the moisture management properties of denim fabrics. According to the results, it was found that the moisture management properties of denim fabric were affected by the type of fiber used as weft yarn and these effects were related to fabric thickness, weight, and density [62]. Kurtulmuş et al. (2018), aimed to design high-performance denim motorcycle pants with improved mechanical and impact wear resistance using different fiber-yarn types and fabric constructions. They aimed to provide standard impact abrasion resistance in the hip, and knee areas of the body. Higher performance was obtained regarding tensile strength and impact abrasion resistance compared to conventional cotton denim fabric by using cotton/Cordura® yarn in the warp and T400 polyester yarn in the weft. The use of thicker yarns and double woven fabrics increased impact abrasion resistance compared to single-layered fabrics [63]. Cordura® fibers are used in technical areas as they are resistant to friction, tear, and crash, and used in combination with different fibers to increase the strength of fabrics [57].

4.2.2. Emana® Fibers

Emana® fiber is used to produce denim fabrics that benefit the body, and these fabrics come to the forefront with more functional features beyond fashion. Emana® fibers are activated by the natural heat of the body. Fibers absorb heat from the body and convert it into far infrared rays (FIR). These rays reduce cellulite in the body and provide a smoother and younger skin appearance. The Emana® technology uses Solvay's intelligent yarn based on polyamide 6.6 embedded with bioactive minerals. Emana® fibers give a very soft and smooth touch to denim jeans. Infrared rays increase blood circulation in the body. Skin roughness and orange peel appearance are reduced. Emana technology has been approved and patented by independent laboratories and institutes; it is Oeko-Tex® certified and therefore not harmful to human health and is compatible with the skin [64]. Emana® technology has been compared with coating and microencapsulation in Fig. 8.

Fig. 8. The comparison of coating (a), microencapsulation (b), and Emana® (c) technology [65]

In the coating or microencapsulation, the effect decreases after washing but the effect of Emana® is permanent. There is a chemical migration to the skin through the fabric in coating and microencapsulation methods, whereas in the Emana®, bio crystals are embedded in the fiber, so there is no chemical transfer to the skin. Denim fabrics produced with Emana® give a better touch than others [64].

4.2.3. Nilit® Sensil® Fibers

Nilit® is a manufacturer of high-quality Nylon 6.6 fibers. The Sensil® series, which is a registered trademark of Nilit®, is also based on Nylon 6.6 Sensil® and soft, high-performance, and durable. Also, moisture absorption is good compared with other

synthetic fibers. This fiber prevents odor formation, which makes it important for denim fabric production and can be perfectly blended with cotton. High-performance Sensil® fibers are manufactured to meet the requirements expected from denim products today. Comfortable Sensil® Breeze series has a cooling effect. Body Fresh prevents the formation of odor caused by bacteria so that users do not need to wash the product very often. Heat series provides a warmer feeling on cold days and denim garments produced with Aquarius series remove moisture out and dry feeling. The Sensil® Innergy series helps to reduce the appearance of cellulite by energizing body cells. Comfort and functional properties expected from denim fabric are provided with the different series of Nilit® Sensil® fibers [65].

4.3. Elastic Fibers

4.3.1. Elastane Fibers

Elastane yarns can be used in all areas, including casual, marine, sportswear, classical clothing, and denim products. The general name of these yarns is elastane in Europe and spandex in Asia and America. Elastane fiber was found by DuPont in 1959 and commercialized in 1962 under the registered trademark Lycra®. Dupont is first in elastane production. General properties of elastane yarns are high tensile strength, resistance to chemicals, high friction resistance and they can be produced as dyed or undyed [66,67]. Elastane combined yarn production methods are four types which are hollow spindle, air system, twist, and core-spun production. The most accepted method is core-spun production. There is elastane fiber in the core of these yarns, and a bundle of staple fibers wound on the elastane in the outer part. All types of staple fibers can be used for the outer layer [1, 68]. Fabric constructions where stretching is increased but permanent elongations, called growth, can be reduced as much as possible during fabric stretching are preferred [68].

The world's second-largest elastane yarn manufacturer is the Hyosung Company in South Korea. The elastane yarns are known under the name of Creora® [66]. Creora® is a polyurethane-based elastane fiber that was started to be produced in 1992 by the Hyosung. The Fit 2 series of Creora® fibers are used for the production of denim fabrics especially and provide both lengthwise and crosswise elasticity [69].

4.3.2. Elastomultiester Fibers

Elastomultiesters (EME) are special yarns produced by simultaneously drawing two different polymers with different viscosities. When these yarns heat, a spring-like structure is formed. Heat-treated yarns gain good stretching and recovery feature with this special structure [70]. Fig. 9 shows the image of the EME fiber, and Table1 gives the comparison of PTT, PET, PBT, and T400 fibers.

Fig. 9 Cross-sectional shapes of the EME fiber [71]

Table 1. Comparison of PTT, PET, PBT, and T400 fibers [72]

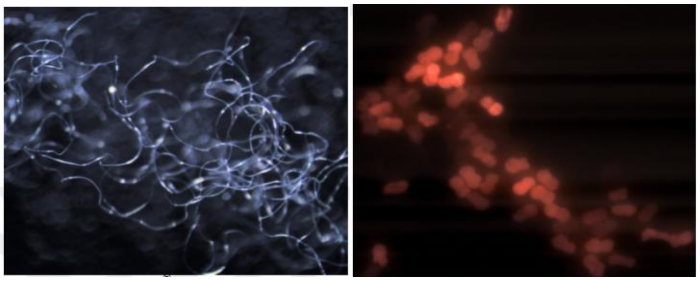
Property	**PTT**	**PET**	**PBT**	**T400**
The density of fibers (g/cm^3)	1.35	1.39	1.32	1.36
The density of amorphic regions (g/cm^3)	-	1.335	1.286	-
The density of crystallin regions (g/cm^3)	-	1.455	1.390	-
Glass transition temperature (˚C)	50	74	20-40	65
Melting point from DSC (˚C)	228-230	253-255	221-226	229
The temperature of thermofixation (˚C)	160	177-188	182-188	160-177
Dyeing temperature (˚C)	100	125-130	100	100-130
Spec. tensile breaking stress (cN/dtex)	2.29	3.795	2.38	3.35
Breaking elongation (%)*	41	16.5	37	274
Elastic elongation (%)	27	21	28	37-68
Modulus of elasticity (cN/dtex)	13.24	42.36	16.42	35.3
Yarn crimp extension (%)**	246	213	233	275
Crimp form	irregular	irregular	irregular	regular, spiral
Yarn liveliness	twisting	twisting	twisting	skill

*Elongation after decrimping **Decrimping was measured by the ASTM D1774 method

Kurban (2019), studied the development of super-stretch fabrics, and for this purpose, 100% cotton and core/dual-core yarns were produced for denim fabrics. T400® and PBT (polybutylene terephthalate) filaments were used in the core, and cotton, cotton/EME, and Modal® fibers were used in the outer layer. Each of the produced denim trousers had different elasticity values, and also a new test device was developed to measure the pressure of the trousers on the human body [70].

4.3.2.1. Polytrimethylene Terephthalate Fibers (PTT)

PTT which has elastic properties is a member of the PET (polyethylene terephthalate) family. PTT can be dyed easier than PET, and it is cheap than polyurethane (PU) based elastic fibers. It also has the best elastic recovery feature compared with all fibers. PTT fibers can be an alternative to PU fibers [73]. Sorona® (Fig. 10) is a biopolymer fiber based on PTT developed by DuPont. Sorona® fiber contains 37% vegetable sources (mainly corn) and it is more environmentally friendly. Less energy is used during production 30% and 40% and less greenhouse gas is spread 63% and 56% comparing with Nylon 6 and Nylon 6.6 [60, 74].



a b

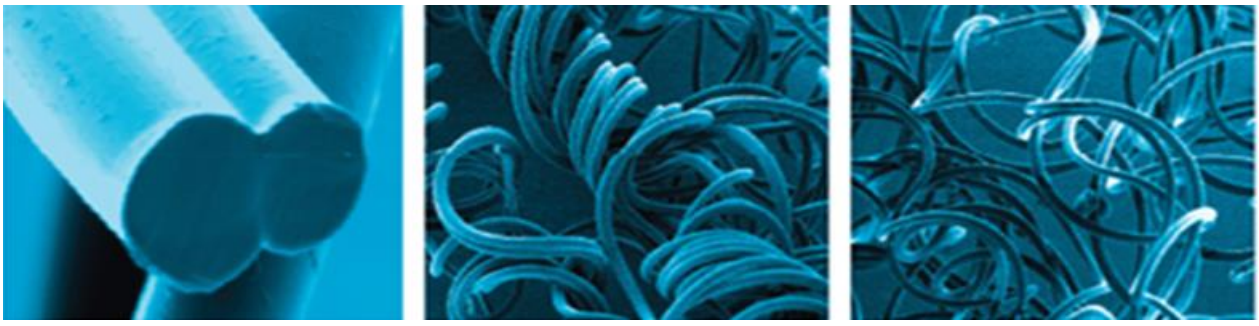
Fig. 10. Crimped structure (20X) (a) and cross-section views (200X) (b) of Sustans® fibers [75]

Sorona® fiber is comfortable, flexible, and has good recovery properties and is used for everyday garments as well as denim fabrics [76, 77]. Sustans® fiber is a staple PTT/PET bicomponent fiber and the PTT part is produced from Sorona fiber. Sustans® is obtained from natural and renewable resources with a clean production process. It has good elasticity and recovery properties and high volume [70]. Özkan (2019), produced denim fabric using 100% cotton and Cotton/Sustans® fibers with different blending ratios and examined the physical properties of them. Elongation, dimensional stability, unevenness, and hairiness of the fabrics with Sustans® yarns were better than the 100% cotton. However, fabric strengths were decreased a little. The optimum mixing ratio was 50/50 Sustans®/Cotton according to the results [75].

4.3.2.2. T400® Fibers (PET/PTT)

Lycra®, Lycra® T400®, Lycra® dualFX™ which contain both Lycra® and Lycra® T400®, are the most commonly used elastane fibers in denim products [68]. Lycra® T400® is an elastomultiester (EME) bicomponent fiber and consists of two polymers with different viscosity. The fibers are produced by the melt spinning. In the standard finishing processes, a helical structure is formed since the polymers in the fiber structure exhibit different shrinkage behavior after exposure to heat. The physical helical structure of this fiber provides long-lasting recovery. This fiber is different from known polyester fibers. Although there is no elastane in its structure, it gains elasticity due to the structural properties of the fiber [78]. Fig. 11 shows the image of the T400® fiber.

In addition to its characteristic elasticity, Lycra® T400® fiber provides moisture balance to help users feel cool and dry and is used in knitted and woven fabrics as well as in the denim industry. In the current denim market, flexible denim fabrics called “dual effect” are very popular. Lycra dualFX™ fabrics with Lycra® and Lycra® T400® fibers are often preferred in denim products [68]. A new generation of elastic fibers is becoming widespread in denim production due to their high-performance properties. However, it is predicted that it will take longer to replace with elastane in denim since they are more expensive and newer fibers than elastane [80].



Lycra® T400® fiber showing the two polymers in each filament creating a snowman-like cross-section

Lycra® T400® fiber off the package

Lycra® T400® fiber after heat exposure

Fig. 11. Lycra® T400® fiber structure [79]

4.3.2.3. Polybutylene Terephthalate Fibers (PBT)

Poly Butylene Terephthalate (PBT) fiber is a member of the semi-aromatic polyester class. The chemical composition of PBT and polyester (PET) are not so different, but the high crystallization rate and low melting temperature properties of PBT are different from PET. Modified new generation polyester with high performance, including PBT, compete with standard fibers because of their advantages. PBT fiber has high elasticity, can be dyed easily in atmospheric conditions, show high resistance to solvents, and staining, and these properties distinguish PBT fibers from other polyester fibers. PBT fiber is more elastic and has better stretch and rebound properties than PET. The importance of PBT fibers is increasing because of their superior properties in the textile industry [70].

4.4. Polyethylene Fibers

4.4.1. Dyneema® Fibers

Ultra-high molecular weight polyethylene fiber (UHMWPE) has very high abrasion resistance and strength values. However, the low melting point limits the use of denim motorcycle trousers at a rate of 100%. Therefore, some manufacturers use UHMWPE by mixing it with Kevlar® or cotton [81, 82]. Dyneema® is a type of high-performance fiber manufactured from UHMWPE and branded by DSM Company. Dyneema® fiber has very high tensile strength and good elasticity [81, 83]. This fiber is used for the production of fabric or denim trousers which are strength and have abrasion resistance [84]. Dyneema® fibers are especially used in the production of motorcycle denim trousers where high wear resistance is needed. The abrasion resistance of the fabric increase with help of these fibers so motorcyclist injuries are reduced and even prevented. Zhao (2017), produced denim fabrics consisting of Dyneema® and cotton, which provide high protection and comfort. Better protection and higher performance were obtained when the ratio of Dyneema® increased [81]. Fig. 12 shows the denim fabric structure produced from Dyneema® and cotton fibers.

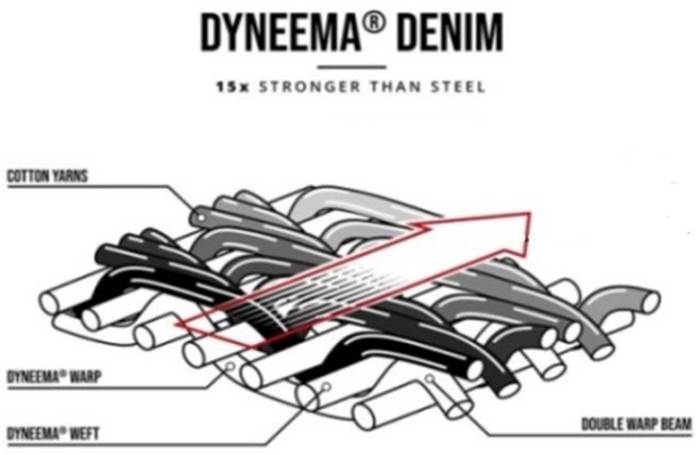


Fig. 12. Denim fabric produced from Dyneema® and cotton [85]

According to studies, denim fabric showed good resistance to abrasion force at a sliding distance of 70 meters for 6.5 seconds when 55% of Dyneema fiber was used [85].

5. CONCLUSION

Trend fibers, which have become widespread in denim fabric production in recent days, have examined according to types of raw materials in this study. Modal® and Tencel ™ fibers are the most preferred regenerated fibers in textiles and this is also true for denim fabrics. Kapok fiber, which is natural cellulosic fiber, has also started to use in denim. The most prominent properties of kapok, mint, nettle, and bamboo fibers are their antibacterial activities. Antibacterial property is important for denim fabrics, however, some studies suggest that the fibers should be used above certain ratios to obtain antibacterial activities. Linen, hemp, and jute are also preferred in the production of denim clothing. However, they are mostly used mixing with cotton or other fibers that have similar characteristics. Pineapple leaf fiber can be preferred for new concepts or collections although it isn't common in the textile industry.

Wool and cashmere are warm fibers due to their physical structure and they are in the class of luxury fibers for denim. They are expensive and blended with inexpensive fibers to reduce the cost of denim products. There are also studies on the use of silk fibers in denim fabrics. Soybean fibers are the antibacterial, soft, and rising star of protein-based fibers. Although it is not common, recently protein-based corn fibers have also been used in jean production.

The most used synthetic fibers in denim are polyester and elastane fibers. New versions of fibers that have various technical features are also used in denim production in addition to polyester, polyamide, and elastane.

Coolmax® and Thermolite®, which are polyester-based fibers used in denim production, are fibers that provide thermal comfort. Coolmax provides comfortable denim by allowing sweat to evaporate rapidly from the body with its channeled cross-section. Thermolite provides a warmer feel with its hollow cross-section in cold weather conditions.

Cordura®, Emana®, and Nilit Sensil®, which are new generation polyamide-based fibers, come to the fore in denim production. Cordura® team combines the strength and durability of nylon with the comfort of cotton. The Emana® technology uses Solvay's intelligent yarn based on polyamide 6.6 embedded with bioactive minerals. Emana fibers absorb heat from the body and convert it into far-infrared rays. These rays reduce cellulite in the body and provide a smoother and younger skin appearance. Nilit® is a manufacturer of high-quality Nylon 6.6 fibers. The Sensil® series, which is a registered trademark of Nilit®, is also based on Nylon 6.6 Sensil® and soft, high-performance, and durable. Moisture absorption also is higher compared with other synthetic fibers.

Dyneema® is a type of high-performance fiber manufactured from UHMWPE and it has high tensile strength and good elasticity. This fiber is used for the production of fabric or denim trousers especially motorcycle denim trousers where high wear resistance, strength, and abrasion resistance are needed.

Demand for flexible denim garments is as high as rigid ones produced without elastane. Elastane fibers can be used as well as elastomultiester fibers which have different chemical contents and high flexibility. Elastomultiesters are produced by special texturing processes and although these fibers have high elasticity, it is estimated they will take a long time to replace classical elastane due to their high cost. Elastomultiesters are listed as T400, PBT, and PTT according to their elastic elongation (%) from high to low.

There are also studies in which they are used together in denim production to take advantage of the superior properties of fibers. Denim clothes are the most indispensable parts of clothing, undoubtedly. Recently, superior performance and functionality are important issues in addition to comfortable and dynamic denim products. Researches will be continued to discover different and new fibers for denim fabric production in the future.

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