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Physical properties of plain and twill woven fabrics produced from carded and recycled cotton yarn

Ham ve geri dönüştürülmüş pamuk ipliğinden üretilmiş bezayağı ve dimi dokuma kumaşların fiziksel özellikleri

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Abstract

Cotton is the leading natural fiber in the apparel and fashion industry. One of the reasons for this high demand is the belief that cotton is an environmentally safe product since cotton is a biodegradable fiber obtained from natural sources. However, contrary to what is conceived, cotton fiber has some ecological drawbacks, both in the cultivation and during processing. Recycling of fibers, such as polyester, obtained from synthetic polymers is widely applied for a long time. Even some synthetic yarns obtained from wastes have been branded. However, in terms of cotton, the recycling ratio does not seem to be as good as synthetic ones. One of the reasons for this situation is the opinion of insufficient quality of recycled or reclaimed cotton products. The purpose of this study was to compare some main mechanical properties of recycled cotton clothing fabrics with the ones obtained from carded cotton and by this way showing the potential of recycled cotton fibers in the clothing industry. Besides that, we summarized the ecological drawbacks of cotton cultivation and processing and reviewed current challenges that the textile industry has to overcome in cotton recycling.

Keywords: Carded cotton, Recycled cotton, Cotton cultivation.

Öz

Pamuk, giyim ve moda endüstrisinde önde gelen doğal liflerden birisidir. Bu yüksek talebin nedenlerinden biri, pamuğun doğal kaynaklardan elde edilen, biyolojik olarak parçalanabilen bir elyaf olmasından ötürü çevre açısından güvenli bir ürün olduğu inancıdır. Bununla birlikte, düşünülenin aksine, pamuk elyafının hem yetiştirme hem de işleme sırasında bazı ekolojik sakıncaları da bulunmaktadır. Sentetik polimerlerden elde edilen polyester gibi liflerin geri dönüşümü uzun bir süreden beri yaygın olarak uygulanmaktadır. Atıklardan elde edilip markalanan bazı sentetik iplikler de mevcuttur. Ancak geri dönüşüm oranları ele alındığında, pamuk liflerinde sentetik liflerde olduğu gibi yüksek bir oran ile karşılaşılmamaktadır. Bu durumun nedenlerinden biri, geri dönüştürülmüş veya geri kazanılmış pamuk ürünlerinin kalitesinin yetersiz olduğu görüşüdür. Bu çalışmanın amacı, geri kazanılmış iplikten üretilen pamuklu dokuma kumaşların çeşitli mekanik özelliklerini, karde pamuk ipliğinden elde edilenlerle karşılaştırmak ve bu sayede geri kazanılmış pamuk liflerinin giyim endüstrisindeki potansiyeline dikkat çekmektir. Bunun yanı sıra, çalışmada pamuk yetiştirme ve işlemenin ekolojik sakıncaları ile tekstil endüstrisinin pamuk geri kazanım sürecinde üstesinden gelmesi gereken mevcut zorluklar da ele alınmıştır.

Anahtar kelimeler: Ham pamuk, Geri kazanılmış pamuk, Pamuk yetiştiriciliği.

1 Introduction

With the industrial revolution, manual labor systems were replaced by mechanized manufacturing and end products started to be produced in vast quantities and cheaper [1]. As being a part of this industrialization textile production and consumption also increased. In 2000 the world's consumers spent around US$1 trillion on clothing [2]. The value of the global women's apparel market reached USD 505 billion in 2015 and is expected to grow at a compound annual growth rate of around 3% until 2020. The global menswear market totaled USD 418.9 billion in 2015 and is expected to reach USD 522.3 billion by 2020, posting a compound annual growth rate of about 4.8% from 2016 to 2020 [3].

As being one of the biggest consumption market, the textile industry is accused of being one of the most polluting industries by producing not only air pollution and waste water from textile processes but also large volume of textile wastes from manufacturing and from consumption [4]. In the European Union (EU), the amount of textiles discarded only by consumers is around 5.8 million tonnes per year and only 1.5 million tonnes (25%) of these textiles are recycled by charities and industrial enterprises [5]. This means that 4.3 million tonnes of textiles are junked in a year just in European Union. Since cotton is the second most consumed fiber [6], it would not be wrong to assume that majority of this waste corresponds to cotton goods.

Today, cotton waste recycling to the higher value-added products is one of measures for both environmental and economic benefits [4]. However, in terms of cotton fiber, the wastes are generally used in landfill and sound insulation. The recycling of cotton fibers has not yet reached the level of synthetics. Studies in the literature on the recycling of cotton have often focused on the importance and sustainability of this fiber. There is not much work focused on the performance characteristics of the recycled cotton yarn and the fabrics produced therefrom. In [7], by using fabric scraps 50% recycled cotton-50%polyester yarns were produced and then this yarn was compared with the virgin yarn having same count. Single jersey fabrics were knitted with these yarns and the test results indicated that there is not a significant difference between the

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fabrics produced from both of them. In [8], the spinnability of blends containing recycled cotton fibers that were obtained by cutting and shredding of scraps were evaluated.

Recycling of textiles containing man-made fibers, such as polyester, is widely applied for a long time. Even some synthetic yarns obtained from wastes have been branded. The present paper gives a brief information about the potential of recycled cotton in apparel industry. First a shortly outline about cotton cultivation, further fiber processing and also their ecological drawbacks were given. Then we continued with the complexity of cotton garment recycling. At the fourth section, we compared some main physical properties of fabrics produced from recycled and carded cotton fiber. And finally, we discussed the possible applications of recycled cotton fibers.

2 Cultivation, processing of cotton fiber and related ecological drawbacks

Cotton is the most widespread profitable non-food crop in the world. The global reach of cotton is wide, but current cotton production methods are environmentally unsustainable [6]. Environmental effects of some fibers are classified as in Table 1 and as can be seen from the table conventional cotton belongs to Class E [9]. In order to understand why cotton is included in this class, we should examine cotton fiber production and further processing steps briefly.

Cotton fiber used in textile is obtained from cotton plant. Planting begins in February in warm climates and in March/April in cold climates. Young cotton seedlings emerge from the soil within a week or two after planting, depending on temperature and moisture conditions. Squares, or flower buds, form a month to six weeks later and creamy to dark yellow blossoms appear in another three weeks. After a while the blossoms fall off and a tiny fertile ovary remains attached to the plant. Then, it ripens and enlarges into a pod called a cotton boll [10]. There are seeds in the boll that can reach up to 60 in number and about 10000-20000 fibers are formed on each seed. After harvesting cotton fibers must be separated from their seeds in order to be used in yarn production and this process is called ginning. A typical gin will process about 12 bales per hour, while some of today's more modern gins may process as many as 60 bales an hour [10]. A number of processes are required in order to obtain clean, strong and uniform yarns. At spinning mills, the yarn production begins with bale opening. Then the process continues with the blending of the fibers taken from several bales and the cleaning of the foreign materials. Other subsequent steps are carding, drawing, roving and spinning where cotton fiber is turned into yarn.

One of the reasons of association between cotton production and severe environmental effects is the use of chemicals during the cultivation of cotton plants. The plant is very prone to attack by certain insects and fungi, so the growth of conventional cottons demands heavy use of pesticides and fungicides. It is estimated that cotton uses only 3% of the world's farmland, but about 25% of the world's pesticides. In addition, before the harvest of cotton, chemicals such as defoliants are also used to cause the leaves to fall off the plants so as not to stain the cotton fibers [11]. Another environmental hazard associated with the production of cotton is the consumption of natural water resources. The amount of water consumed can reach 29 m^3 per kilogram of cotton [12]. Moreover, in pretreatment process, cotton fiber must be subjected to a NaOH treatment before it is made into a textile product in order to dissolve waxy outer layer and to improve the performance characteristics [11]. In addition, the carbon release during the growth and processing of cotton fiber is even greater than that of some synthetic fibers (Figure 1).

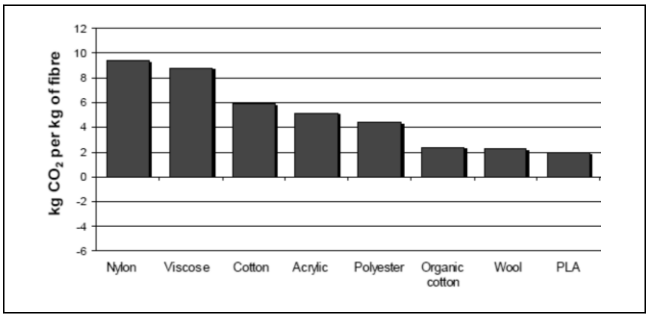


Figure 1. CO_2 emissions of some fibers [13].

3 Difficulty of cotton recycling

Any kind of yarn, fabric and cloth containing cotton fiber must be recycled to the textile industry due to the above-mentioned reasons. Textile wastes are divided into three groups [1] according to their processing difficulties. First group is trashy waste which requires cleaning before reprocessing, examples are blow room wastes, carding waste, card flat strips and filter waste. Wastes which requires no further cleaning are called clean waste and comber waste, card, draw frame and combed sliver waste, filter waste from draw frames, speed frames, ring spinning frames and rotor spinning machines can be given examples to this group. The last group contains wastes that are the most difficult to recycle and they are called hard waste. This group of wastes require opening on special machines and twisted roving, yarns, textile fabrics and garments can be given as examples [1].

Cotton wastes are mostly in the form of clothing; therefore, they are included in the hard waste group that is difficult to recycle. In order to recover any fiber from textile garments of fabrics, textile wastes must firstly turn into open and separated usable fibers [14].

Table 1. Environmental effects of some textile fibers [9].

Class-A	Class-B	Class-C	Class-D	Class-E
*Recycled cotton	*Tencel®	*Conventional hemp	*Virgin polyester	*Conventional cotton
*Recycled nylon	*Organic cotton	*Ramie	*Polyacrylic	*Virgin nylon
*Recycled polyester	*In conversion cotton	*PLA	*Modal®	*Rayon
*Organic hemp		*Conventional flax		*Bamboo viscose
*Organic flax				*Wool
				*Generic viscose

(Silk, organic wool, leather, elastane, acetate, cashmere wool, mohair wool and bamboo fibers are not yet classified).
(Class A contains the least harmful fibers in terms of environment whilst Class E contains the most harmful fibers in terms of environment).

For the process, a so called Garnett machine is used, which consists of rotating drums with metal pins that destroy the textile structure [15]. This step is of course not the solution for the transformation of all cotton-containing fabrics since most of the garments have accessories on it garment such as zipper, snap fastener, button and artificial leather. It is necessary to separate these materials so that the cotton wastes can be decomposed and obtained fibers once more spun in order to form yarn. Having blended fiber construction is the other problem in the transformation of garments into individual fibers. The most prevalent blend is cotton/polyester. Separation of cotton/polyester fabric into its individual components is difficult and mechanical separation is not possible with existing technologies. Some chemical separation methods may be applied but they require harsh processing parameters [16]. For instance, polyester (PET) can be dissolved easily in dimethyl sulfoxide and this chemical can be used as reagent for separating and recovering polyester/cotton fabrics by dissolve them at 185-194°Cfor 60 minutes, then recovering the cotton fibers by filtering and recovering polyester from the solution. In order to separate and reclaim mixed plastic materials some machines were developed one of which is called CENSORTM [14]. Similar technologies should also be developed for cotton/polyester blends. In addition, the application of different colors on clothing is one of the problems that must be overcome.

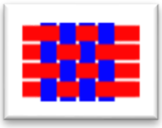
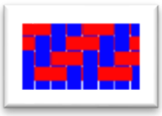
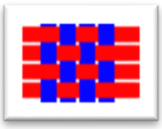
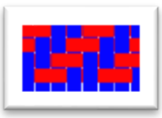
4 Experimental

Current research focuses on some main mechanical properties of recycled cotton clothing fabrics. The paper also makes a comparison of recycled cotton fabrics and the ones obtained from carded cotton yarn in terms of these properties. For this aim, the recycled Ne_c 18/4 cotton yarn was provided from a recycling company located in Uşak, Turkey. The recycling company produces recycled cotton yarn by opening textile wastes and turning them into separated fibers by Garnett machine. In order to make a comparison with a carded yarn, Ne_c 18/4 carded cotton yarn was chosen because of its widespread use. With recycled and carded cotton yarn, two commonly used woven fabrics (plain and 2/2 twill) were manufactured on a handloom. No finishing process was applied to fabrics. The specifications of the fabric samples used in the study are given in Table 2.

Prior to testing, each sample was conditioned under standard atmospheric conditions (20 °C ± 2 °C and 65% ± 4% RH) at least for 24 hours. To characterize the physical behavior of fabrics and make an accurate comparison, widely used tests were chosen.

Tensile tests were conducted on Zwick Roell ZO10 testing machine according to ISO 13934-1 breaking strength, strip method. From all fabric types, 5 samples were taken in the weft and warp direction. During sample preparation, it has been ensured that the samples to be tested do not contain the same weft and warp threads. Woven fabric specimens were 70 mm wide and at least 350 mm long. By pulling 1 cm yarn from each edge, samples having 50x350 mm dimensions were obtained. The test speed specified in the standard for the test is 100 mm/min. The distance between the jaws was adjusted as 200 mm, and the width of the jaws was 50 mm.

Table 2. Properties of the fabrics.

Fabric Code	Yarn Type	Construction	Warp/weft Density (threads/cm)	Mass per Unit Area (g/m^2)	Thickness (mm)
F1	Carded cotton yarn	Plain 	10 20	215	0.96
F2	Carded cotton yarn	Twill 2/2 	10 20	267	1.34
F3	R.* cotton	Plain 	10 20	227	1.13
F4	R.* cotton	Twill 2/2 	10 20	281	1.70

*R. = Recycled.

Bending rigidity reflects the flexibility of the fabric and higher bending rigidity values indicate greater resistance to bending motions [17]. Handle properties of fabric specimens were carried out in circular bending rigidity tester, developed according to ASTM 4032. In this method, the force which is generated while pushing a fabric specimen through a ring is measured [18]. A plunger of 25.4 mm (1 in) diameter pushes the fabric through a 38 mm (1.5 in) diameter orifice for a distance of 57 mm (2.25 in) and the maximum force is recorded [19]. So, the higher the value, the stiffer is the fabric.

Abrasion and pilling performance are two of the most important mechanical characteristics of fabrics [20]. Martindale tester is used for both of the tests. In abrasion test, controlled amount of abrasion is given between fabric surfaces. The small test specimen is positioned on a large abradant and then cycled backwards and forwards in a Lissajous motion producing even wear. A force of 9 kPa is applied to the top of the specimen to hold it against the abradant [19]. The abrasion resistance test was carried out according to ISO 12947-2 standard. For assessment, the specimens were examined at 1000 cycles intervals to see whether thread breakage occurred.

Pilling tests were also conducted on Martindale test machine according to TS EN ISO 12945-2 standard for 2000 cycle. The specimens are rubbed on their own fabrics at certain number of turns during this test. One of the samples is placed on the sample holder and the other is placed on the bottom pilling table. For this aim, the lower samples are cut at a diameter of 140 mm and the upper samples are cut at a diameter of 90 mm. The instrument subjects specimens to a rubbing motion in a straight line that widens into an ellipse and gradually changes into a straight line in the opposite direction. This pattern of rubbing is repeated until fabric threads are broken or until a shade change occurs in the fabric being tested [19]. The pilled fabric specimens were then compared with standard pilling test images to determine the pilling grade on a scale from 1 (most severe pilling) to 5 (no pilling).

5 Results and discussion

Tensile strength is the measure of the maximum load a fabric can withstand before it breaks. At this time, the elongation in the fabric comes to the nature, and the prolongation is called the breaking elongation. Breaking strength results of fabrics are given in Figure 2.

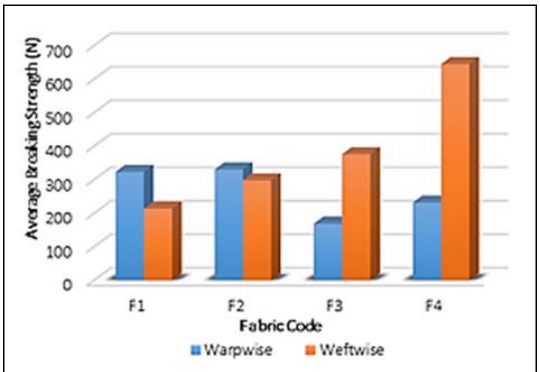


Figure 2. Average breaking strength test results.

Both of the recycled cotton fabrics showed better tensile strength in the weft direction. The weft yarn density is higher than the warp yarn density. This case is probably the reason of the difference. However, similar situation is not observed in carded cotton fabrics. In order to understand the reason for this contradiction, it is necessary to work with more yarns and different fabric structures.

Bending rigidity is a significant property of textiles that influences their further behavior, for example draping and wrinkling [21]. As the handle of the fabric becomes stiffer, the drapability decreases. Moreover, stiffness affects the formability and sewability of the fabric. It is possible to say that the smaller the value obtained from the test, the better the softness of the tested sample. The results of the bending rigidity test carried out in the study are given in Figure 3.

The bending rigidity values of twill woven fabrics were the same for carded and recycled cotton fabrics. However, in plain woven fabrics, the recycled cotton fabric showed lower values, indicating that it is more drapeable and the handle is softer.

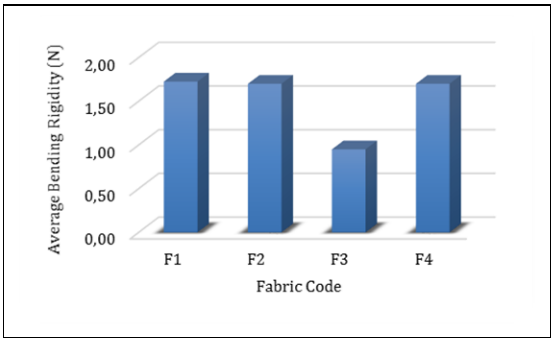


Figure 3. Average bending rigidity values.

The results of the abrasion test can be evaluated in different ways. Abraded test samples can be either compared in terms of thickness and weight differences after a certain number of turns, or they can be evaluated according to cycles at which first yarn breakage occurs. In this study, the test device was stopped after certain cycles and the fabrics were inspected whether there were any yarn breaks. Plain and twill fabrics produced from carded cotton yarn showed yarn breaks in the 17500th and 12500th cycles, respectively, while plain and twill fabrics produced from recycled cotton yarn did not exhibit any yarn breaks even at the 20000th round (Table 3). Fabric construction, thickness, weight, the number of yarn (thread density) and interlacing per unit area are the fabric properties affecting abrasion [22]. Although carded cotton fabrics showed higher tensile strength values in warp direction, the reason of their poor abrasion resistance is probably their slightly lower fabric thickness and weight.

Table 3. Abrasion resistance of the fabrics.

Fabric Type	Abrasion Resistance
F1	17500 cycles
F2	12500 cycles
F3	No damage is observed
F4	No damage is observed

Pilling can be defined as emerging of the loose fibers from the fabric surface and the formation of small fiber balls as a result of rubbing and washing. These fibers, which are released by the influence of mechanical movements in particular, become small fiber knots or groups of fibers adhered to the fabric by several fibers. The recycled cotton yarns have higher hairiness than the carded ones because of their higher short fiber content. These short fibers can easily come out from the yarn and form pills during rubbing action. This is likely the reason why the pilling performance values of recycled cotton fabrics are relatively low (Figure 4). On the other hand, since the float yarn ratio is lower in plain woven fabrics, they exhibited better pilling performance than twill fabrics.

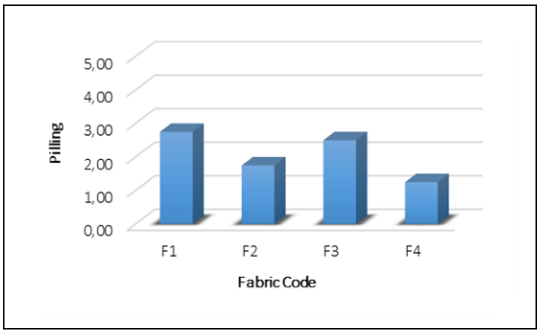


Figure 4. Pilling test results.

6 Conclusion

To produce one kilogram of cotton fiber, approximately 2.4 kg of raw cotton should be harvested. In Turkey, every year, 160.000 tons of industrial cotton textile wastes go to trash without being utilized and the amount of raw cotton to be harvested in order to obtain this amount is 384.000 tons [23]. Therefore, despite all the difficulties mentioned in this study, cotton wastes must be recycled back to the textile industry. Also the results obtained have shown that, if the yarn density of the fabric is increased, the tensile strength of recycled cotton fabrics can be improved. The recycled cotton fabrics showed much better abrasion resistance; but due to their hairy yarn structure they showed lower pilling performance than carded cotton fabrics. Besides that, woven fabrics produced from recycled cotton yarns displayed lower bending rigidity which is an advantage in terms of drapability and clothing comfort. The results of the tests gave clues that woven fabrics made from recycled cotton could be an alternative in the apparel industry. Certainly, in order to reach a more precise and general conclusion, it is necessary to work with more yarns and different fabric structures. Hairy yarn structure of recycled cotton yarns and the drapability of fabrics made from them, can give a potential application in thicker and coarser fabrics like flannel lumberjack shirts, fleece jackets and jogger waist seasonal trousers.

7 Author contribution statements

In this study, Gülşah PAMUK was involved in brainstorming and fabric production, while Esra Zeynep YILDIZ was involved in analysis. Both authors contributed to the literature review and analysis of the results. This work was funded by Ege University as a BAP (Scientific Research Projects Coordination) Project with the project number 16-EAMYO-002.

8 Ethics committee approval and conflict of interest statement

There is no need to obtain permission from the ethics committee for the article prepared. There is no conflict of interest with any person / institution in the article prepared.

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