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Quality properties of recycled yarns obtained by recycling fabrics produced from virgin yarns

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ABSTRACT

In this study, first of all, single jersey fabric scraps knitted from Ne 30/1 (19.7 Tex) cotton yarns were obtained. These scraps were recycled in the rag puller machine without mixing with any other products. Yarn production from recycled fibers was made by open-end spinning machine and Ne 30/1 yarns were systematically produced again. By comparing the test results of the initial state of the yarns and the test results after the recycling process, the impacts of the recycling process of the single jersey fabric knitted from Ne 30/1 cotton yarns on the yarn performance properties were presented objectively. Yarn unevenness of the recycled yarns increased due to the decrease in fiber lengths due to the damage given to the fibers during mechanical recycling.

Keywords: Textile recycling; Recycled yarn; Cotton; Open-end; Textile waste; Yarn unevenness.

1. INTRODUCTION

It is estimated that the world population will reach 7 billion now, approximately 10 billion in 2050, and 20 billion in 2100, which is about 3 times the current population. When we take this into account, it becomes clear that we need a new way of life and a new perspective. For 20 billion people, first of all, we need clean water resources that are potable and can be used in agriculture, agricultural areas for food, clothing and of course, raw materials for consumption such as communication, transportation and housing, and therefore we need to develop solutions for more efficient use of natural resources from production to consumption [1].

Recycling has become an increasingly important issue in the world due to the depletion of natural resources and the increase in waste disposal costs. Regulations such as carbon footprint, Fit For 55, EU Green Agreement, Paris Climate Agreement, which are on the agenda in the world, always include environmental measures. There is a need for research in the literature on the importance of recycling and sustainability in every field in the world.

Recycling is defined as the conversion of the components in the waste into other products or energy by physical, chemical or biochemical methods by taking advantage of the properties of the wastes [2]. With another definition; recycling is the integration of recyclable waste materials, which are not used in any way, to the production processes as raw materials by various recycling methods [3, 4]. These materials are textiles, paper, glass, plastic, motor oil, batteries, concrete, aluminum, organic wastes, electronic materials and such wastes [5]. Today, recycling has taken on an ethical feature rather than being a waste management approach and has become one of the most important symbols of environmental awareness in societies [6]. Considering the natural energy resources that have been depleted all over the world in recent years and increasing raw material costs, manufacturers, who act with environmental awareness and the idea of being able to survive in the economic sense for a long time in almost every branch of the industry, take important steps in terms of recycling products in order to reduce their production costs [7].

The need for sustainability and environmental protection is increasing day by day. At this point, it is important to reuse raw materials and leave as little waste as possible to the nature. For this reason, textile and apparel products should be evaluated and recycled [8]. Sustainability in the textile and apparel industry includes all materials being organic, environmentally friendly and recyclable, including the process of formation of the product from the raw material [9]. ÜTEBAY *et al*. [10] investigated the effects of cotton textile waste properties on recycled fiber quality and they showed that the recycled fibre quality and the resultant yarn properties are associated with the waste fabric properties and shredding parameters. AWGICHEW *et al*. [11] analysed

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the recycled fibers effect on the yarn and woven fabrics as their proportion increases, and their results showed that the yarns and fabrics produced from recycled fibers blended with virgin cotton are suitable for applications where the strength of yarns and fabric are less critical. MEMON *et al*. [12] examined the properties of the yarns produced from recycled cotton fiber blends for proportion optimization and to check whether they can be used for denim fabric production. The physical properties of the denim fabric confirmed that the recycled fibers have wearable quality. GUN *et al*. [13] investigated the dimensional and physical properties of socks produced from recycled fibers. Ne 20 recycled yarns were produced by blending the fibers produced from cotton clothing waste and virgin polyester fibers at a ratio of %50/50. These yarns were compared with 100% virgin cotton yarns of the same number. WANASSI *et al*. [14] worked on low-cost yarn production by providing added value to recycled fibers. They produced yarn in different numbers using 50–50% cotton and waste cotton. It was observed that the properties of these yarns showed similar physical properties when compared to the 100% virgin cotton yarn produced as the control group. VADICHERLA and SARAVANAN [15] investigated the characteristic properties of mechanically recycled polyester – cotton blended yarns. They produced yarns in 3 different numbers and 3 different blend ratios, except the control groups. It was observed that increasing the recycled polyester content lead to increase strength, elongation at break and hairiness, while reducing unevenness, thin places, thick places and neps. BORMAN and SUN [16, 17] comparatively examined the tear strength and abrasion resistance properties of denim fabrics produced from virgin cotton fiber and recycled cotton fiber. ONER and GUN [18] in their study investigated the quality properties of open-end yarns made from recycled fabric waste and virgin polyester blends. In the study conducted by REPON *et al*. [19], they investigated the effect of rotor speed and rotor diameter on yarn properties by producing Ne 12/1 open-end yarns using 65% virgin cotton fiber and 35% recycled cotton fiber. In the study conducted by SHARMA and GOEL [20], nonwoven surface samples were produced by needling method, using different ratios of recycled cotton and recycled polyester fibers (30%–70%, 50%–50% and 70%–30%). As a result of the study, the highest abrasion, burst and breaking strength value (in the machine direction) was obtained in the nonwoven surface samples obtained from the mixture at the rate of 30–70%, and the highest bending length value was obtained at the mixture rate of 50–50%. AWGICHEW *et al*. [21], analyzed the effects of the use of recycled cotton fiber on the properties of OE-rotor spun yarns and hand-woven fabrics produced from these yarns. In a different study, OE-rotor yarns with different mixing ratios were produced from denim waste by RADHAKRISHNAN and KUMAR [22]. They obtained woven fabrics from these yarns and examined the mechanical, physical and comfort properties of the fabrics. They concluded that the products are sustainable and usable in the clothing industry. HASANI *et al*. [23] 24 investigated the determination of various machine parameters by the Taguchi method, required to produce quality OE-rotor yarn (Ne 12/1, Ne 16/1 and Ne 20/1) from recycled fibers.

It is obvious that recycling textile products are ecologically beneficial. However, no studies have yet been conducted on how yarn performances change after recycling. Therefore, such information is not available. As a general rule, post-recycling performances are considered to decline. However, the fact that this decrease has not been calculated quantitatively creates a deficiency in the sector. In the event that this problem is solved, it will be useful to have more descriptive information about the economic values of recycled yarns, as well as to have information about the performance change of the fabric for the manufacturer and the consumer. The current research on this subject is very limited and does not include a comparison about before and after recycling. From this perspective this study concretely addresses the changes that will occur in the performance of a textile material after it is recycled. In this way, a scientific contribution will be made to understand the change in performance properties of a textile material after mechanical recycling.

2. MATERIALS AND METHODS

Within the scope of the study, Ne 30/1 (19.7 Tex), 100% cotton open end yarns were selected. The purpose of selecting cotton yarns is the widespread use of cotton yarns in the production of textiles. The quality characteristics of the cotton fibers used in the production of these selected cotton yarns were measured. After yarn spinning, the properties of these virgin cotton yarns were measured. Afterwards, the wastes of the single jersey knitted fabrics produced from these virgin cotton yarns on the circular knitting machine were collected. These knitted fabric wastes were recycled and turned into recycled fiber by mechanical recycling method. Open end yarns were produced from these recycled fibers with a similar twist number and count as Ne 30/1. Thus, it is aimed to examine the differences between the physical performances of cotton yarns before and after recycling.

Uster HVI Testing System was used to determine all the physical and quality properties of the South East Anatolian regions of Turkey's cotton fibers used in the study. The cotton samples were collected from cotton bales of the blends, which were prepared for the production of yarns to be used in this study. The mean properties of the cotton fiber blends formed for the virgin cotton yarns used in this study are given in Table 1.

Table 1: The quality properties of the virgin cotton fibers used in the study.

PROPERTY	BLEND FOR NE 30
Neps	195.12
Spinning Consistency Index (SCI)	144.00
Micronaire	4.76
Maturity Index	0.88
Length (mm)	28.97
Uniformity	84.05
Short Fibre Index	7.20
Strength (g/tex)	32.60
Elongation (%)	11.01
Moisture Content (%)	6.40
Reflectance (Rd)	67.40
Yellowness (+b)	8.60
Trash Area (%)	1.49
Trash Grade	7.00

Table 2: The measurement results of the virgin cotton yarns.

	T/m	U_m%	CV_m%	THIN –50%	THICK +50%	NEPS +280%	RKM	ELONGATION %
Mean	925	9.63	12.18	0.20	16.82	5.20	18.67	5.91
CV%	1.21	0.86	0.96	136.93	11.34	24.13	2.64	6.09

Table 3: The properties of single jersey fabric.

	MASS PER UNIT AREA (g/m^2)	THICKNESS (mm)	WALES/cm	COURSES/cm	LOOP LENGTH (mm)
Mean	165.00	0.57	14	20	2.96
CV%	0.74	4.30	0.12	0.22	1.6

Uster HVI measurements of recycled fibers obtained by recycling fabric scraps could not be carried out because these fibers contain high amounts of dust and thread particles.

Physical properties of the virgin cotton yarns prepared for knitting used during this study, which were measured by the Uster Tester 3, were given in Table 2.

The knitted fabrics were produced on Karl Mayer single plate circular knitting machine (machine fineness (Fein): 28, machine diameter (Puss): 32) from these virgin cotton yarns, given their properties. Washing, softening and indanthrene dyeing processes were applied to these knitted fabrics. The properties of the produced knitted fabrics were shown in Table 3. Afterwards, the apparel processes of these knitted fabrics were followed. Fabric wastes occurring in the apparel cutting department was tracked one by one and collected as fabric waste. Thus, textile wastes were obtained, with all details known from the fiber stage to the fabric stage.

By following knitted apparel processes, 200 kg of pre-consumer textile wastes consisting of cutting department wastage were collected. Pastry paper pieces, labels and accessories were sorted from the fabric scraps. The fabric scraps selected by the discrimination process were cut in a Balkan DTA62 Guillotine Cutting Machine. Then they were subjected to the opening process in Balkan DT30 Mega Pulling Machine (Figure 1). The recycled fibers after pulling process are shown in Figure 2.

Figure 1: Recycling of the single jersey fabric scraps in the rag puller machine.

Figure 2: Recycled fibers and single jersey fabric scraps.

The blend was prepared from recycled fibers fed with Balkan B10 Bale Opener and Balkan Dt80 Box Room, and went through carding and draw frame processes respectively. For these processes, Trützschler TC 19 Carding Machine and Rieter RSB-D50 Draw Machine were used. Six doublings and six drafts were applied during drawing passages at 400 m/min, and 5.5 ktex slivers were produced. The recycled yarns were spun on a Saurer Autocoro 8 open-end spinning machine with 32 mm rotor diameter, 120000 rpm rotor speed, 9500 rpm opener roller speed to produce Ne 30 (19.7 tex) yarn counts (Figure 3).

In order to conditioning the yarn samples produced in this study, the samples were kept in the laboratory for 24 hours at standard atmospheric conditions (20 ± 2 °C, 65 ± 2% RH) before the tests according to ASTM D1776/D1776M-15 [24]. As yarn quality properties, unevenness, imperfections (thin places, thick places and neps), yarn tenacity and elongation values of the yarn samples were measured. Unevenness, imperfections properties of the yarn samples were measured on Uster Evenness Tester 3 at testing speed 400 m/min according to ASTM 1425 [25] and yarn tensile properties were tested on Uster Tensorapid 4 Tester in accordance with EN ISO 2062 [26]. The obtained results were evaluated with a variance analysis by using SPSS 22.0 statistical software.

3. RESULTS AND DISCUSSIONS

In this study, the performance properties of knitted fabrics produced using original yarns (first-use yarns) and recycled yarns obtained by recycling the same fabrics were compared. By comparing the test results of the initial

Figure 3: Recycled fiber was spun into yarn on the Saurer Autocoro 8 open-end spinning machine.

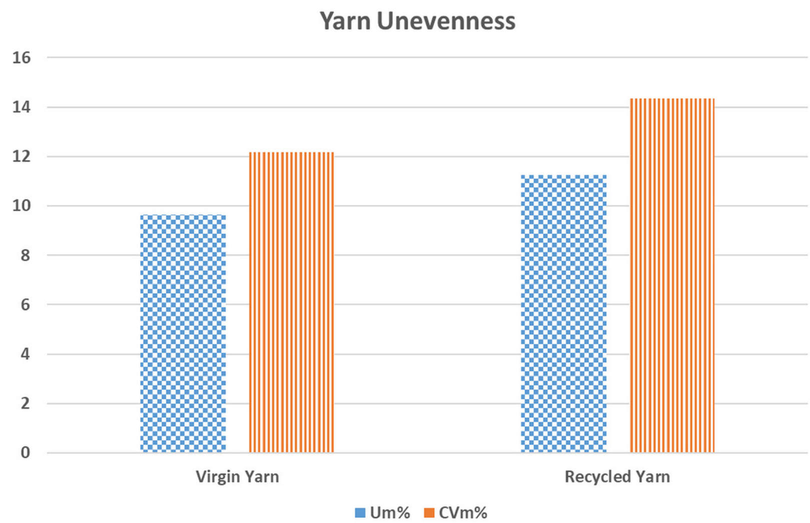

Figure 4: Unevenness results of the yarns.

state of the yarns with the test results after the recycling, the effects of the recycling process on the yarn performance properties. Thus, the performance change in recycled yarns will be understood concretely.

The percentage mass deviation of unit length (U_m%) and the coefficient of variation of mass per unit length (CV_m%) give information about yarn unevenness. The increase in the percentage value indicates that the quality of the yarn deteriorates. The unevenness measurements of the virgin and recycled yarns used in this study are illustrated in Figure 4.

As seen in Figure 4, the unevenness of recycled yarns is higher than the virgin yarns. These conditions show how much the yarn unevenness can increase in Ne 30/1 yarns made after the recycling process of single jersey fabric made from Ne 30/1 virgin yarns. This increase in unevenness occurred due to the decrease in fiber lengths due to the damage given to the fibers during mechanical recycling. As AWGICHEW *et al*. [21] stated that, unevenness and proportion of recycled fibers show parallel increase due to the increasing amount of short

Table 4: The imperfections of the yarns.

YARN TYPE	THIN PLACES (–50%)	THICK PLACES (+50%)	NEPS (+280%)
Virgin	0.2	16.82	5.2
Recycled	12.5	105.5	206.5

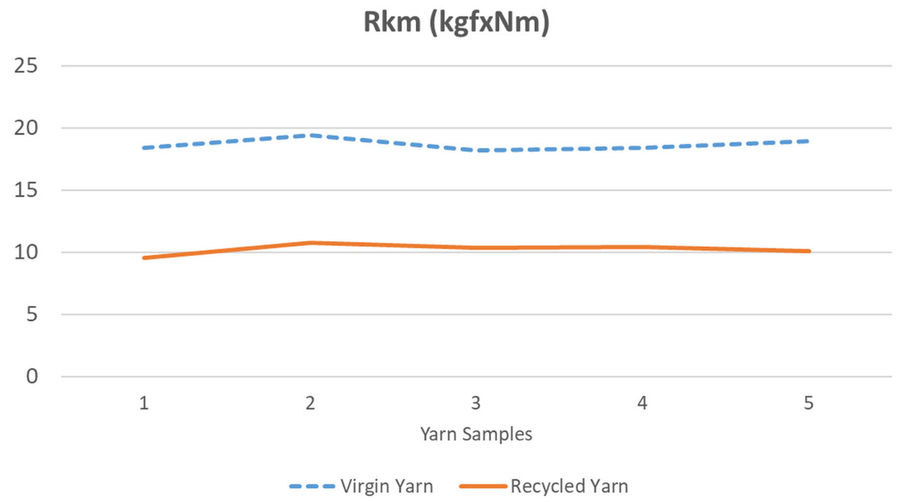

Figure 5: Tenacity results of the yarns.

fiber in the yarn. According to the variance analysis it is seen that unevenness values of the yarns are significantly different between each other statistically ($p < 0.05$).

In terms of rotor spinning, imperfections as thin, thick places and neps are important indicatives that affect the appearance of the yarns and product quality [27]. Yarn imperfections are expressed as thin places, thick places and neps. Thin place (–50%/km) refers to the place with 50% or less of the average yarn thickness. Thick place (+50%/km) is considered as a thick place of 150% (1.5 times) of the average yarn thickness. Neps is expressed as a thick place of 280% of the average yarn thickness in rotor yarns. Thin place (–50%/km), thick place (+50%/km) and neps (+280%/km) test results were obtained from the yarn quality values and were compared with the virgin yarn values. The imperfection results of the virgin and recycled yarns are given in Table 4.

The findings obtained show that after the recycling process, especially the thick place values of the yarns increase significantly. It is understood that thick place imperfections will be more common in the recycling of yarns. When fabric scraps are opened and recycled, the remaining parts that are not fully decomposed may cause these thick place imperfections.

Yarn tenacity is expressed as the ratio of the breaking force of the yarn to the count of the yarn and is shown in units such as g/tex, cN/tex, Rkm (kgfxNm). Strength value is the most important feature that determines the usage area of textile materials [28]. For this reason, it will be very important that the strength value will change significantly when recycling a textile material. Measurement results of different samples of recycled and virgin yarns are given in the Figure 5. Different measurement results are given to better see the trend in strength change.

When the strength results are examined, it is seen that the recycled yarns experience a significant loss of strength compared to the virgin yarns. As TELLI and BABAARSLAN [29] stated that low tensile strength is related to poor fiber length uniformity. HALIMI *et al*. [30] also showed the relationship between recycled cotton and short fiber index. There are also studies in the literature regarding the strength loss of recycled cotton [24, 31–34]. However, with the results found in this study, it will be possible to predict the loss of strength that will occur when passing from virgin to recycled yarn, and thus the usage area of the recycled yarn can be determined. According to the variance analysis it is seen that tenacity values of the yarns are significantly different between virgin and recycled yarns statistically ($p < 0.05$).

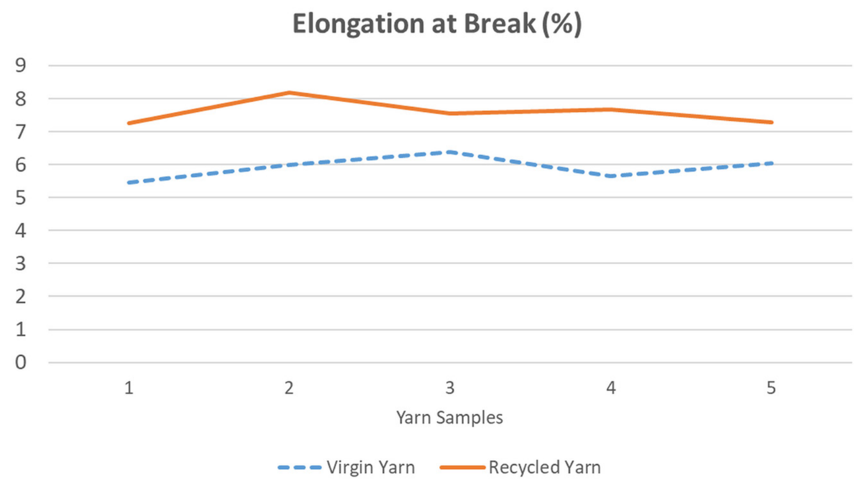

Figure 6: Elongation results of the yarns.

Elongation at break is the percentage of the extension that occurs during the breaking of the yarn. Recycled yarn elongation values were obtained by test results and compared with the virgin yarns. And these results for different yarn samples are given in Figure 6.

When the elongation values are examined, it is seen that the elongation ability of recycled yarns is superior to virgin yarns. Looking at the percentages of change, it is seen that the the elongation value increased by 28.43% for recycled yarns. This result is compatible with the literature. Researchers have also found that indicated that yarn containing recycled cotton fiber has a higher elongation at break than virgin cotton [29]. This shows that recycled yarns are more suitable for knitted fabrics where relatively lower strength and higher elongation properties are expected. The effect of yarn type on the elongation at break was found statistically significant ($p < 0.05$).

4. CONCLUSIONS

Today, one of the most important problems in textile recycling is traceability. Many companies, institutions and associations deal with textile waste collection activities and separation processes, but they have difficulty in monitoring the process from the moment a textile waste is produced to its recycling. The most prominent aspect of this study is that all stages of the production of a textile product from start to finish and the recycling of waste generated during production recycling to the textile product are followed. In this study, single jersey fabric produced from Ne 30/1 cotton yarn was used. As can be seen from the performance characteristics of the yarns obtained before and after the recycling of the single jersey fabric, it has been determined numerically how much the yarn quality is affected and how much performance loss is experienced due to the breaking and shortening of the fibers. By applying this study to other fabric and yarn types, approximate quantitative standards may be obtained.

When the results obtained were evaluated, it was determined that the properties of the recycled yarns from the waste of the knitted fabric produced with virgin yarns deteriorated in terms of unevenness, impurities, especially thick place defects and strength, but were better in terms of elongation at break. This shows that when recycling fabric waste, it would be better to produce thicker yarns than the original and to focus on knitted fabrics as the final product.

Predicting how the yarn properties change according to the yarn and fabric type used for recycling and the approximate estimation of the final properties of the yarn to be produced without the need for trial studies will provide great convenience, prevent unnecessary cost increase, and facilitate production with the desired properties. In this way, according to the expected characteristics of the recycled yarn to be produced, it will be known beforehand that which type of fabric scraps will provide optimum benefit. With the information obtained as a result of the study and by expanding this information with future studies, the statistical data necessary for the standardization of textile recycling may also be provided. The results of the study are expected to be beneficial to science and industry representatives who conduct research on textile recycling and sustainability. Future studies are planned to produce knitted fabrics from recycled yarns with different construction and content types, to compare virgin knitted fabric with recycled knitted fabric.

5. ACKNOWLEDGMENTS

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