INDUSTRIAL COTTON WASTE: RECYCLING, RECLAIMED FIBER BEHAVIOR AND QUALITY PREDICTION OF ITS BLEND

Wanassi Béchir2, Ben Hassen Mohamed1,2 Azouz Béchir2

[1] *College of Engineering: Industrial Engineering Department. Taibah University Saudi Arabia*
[2] *Laboratory of textile engineering of iset ksar-hellal, University of Monastir. Tunisia*

ABSTRACT

This paper aims to explore the use of industrial cotton waste as an alternative of virgin cotton and to understand the effects of recycling process in the global quality of reclaimed fiber. It also tries to predict the quality of the mix of recycled fiber with virgin cotton using mathematical approach. The global quality of recycled fibers was investigated using single criteria like Mean Length (ML), Span Length (SL2.5)… and with complex criteria such as Fiber Quality Index (FQI) and Spinning Consistency Index (SCI). The blending fibers properties were simulated mathematically. The ML, SL2.5, Upper Half Mean Length (UHML), Upper Quality Length (UQL), Fineness and Uniformity Ratio (UR) were analyzed according to the simulation results which were reported by experimental analysis using R^2 as correlation coefficient. The optimum quality of reclaimed fiberswasselected with the consideration of FQI and SCI plots. The blend of recycled fibers with Malian fibers was selected as the beneficial mix. Under the optimum recycling condition, the effect of recycled fibers (40%, 50%, 60% and 75%) on the irregularity and the tenacity of blended yarn were evaluated. It was shown that the CVm %, Thinness 30%/Km, Thickness 30%/km, Neps 280%/m andHairiness % of obtained yarn increase by 20%, 13%, 32%, 50% and 20%, respectively, when the ratio of recycled fibers increase from 40% to 75%. While the tenacity of obtained yarn decrease by 16%.The use of yarn based on recycled fibers suggests the recent and progress demand for special DENIM woven in particular is met, at least partially, through this way.

Keywords: Recycled fiber, Blending, Cotton waste, Mathematical approach, SCI, FQI.

Corresponding Author: Ben Hassen Mohamed, benrayeen@yahoo.com, m.benhassen@taihbahu.edu.sa.

1. Introduction

Cotton fiber is the most commonly utilized fiberin the textile industry(1). It is mainly usedin spinning to produce ring or open-end yarn forweaving and knitting applications. The annual production of cotton fiber is about 26 million tons(2). In a 2016, the yield of cotton was about 823 kg per second and that 80% of the world's cotton production is grown in the Northern Hemisphere.The culture of cotton needs massive amount of water and its cultivation contributes to more than 57% of the total water utilization in the agricultural sector(3). In addition to that, around a quarter of the total quantity of pesticidesis being used in cotton agriculture. This poses significant damage upon human health and present toxicological problems for all organisms(4). To summarize, the increasing use of cotton fiber in textile industry couldreduce aquatic reserves as well as increase the planet's pollution.It is therefore necessary to find and adopt an alternative source for cotton fiber as a natural resource through recycling cotton waste (5,6) or using the post-industrial waste (7,8).

Recently, several works have investigated the use of an ecologicalapproach to produce pesticide-free cotton fiber (9) and to reduce the water consumption. During its harvesting, vegetation cycle and transportation, the ecological cotton was treated with eco-friendly substances(10). However, the cost of ecological cotton was more expensive than ordinary cotton which resulted to the significant increase in the total cost of the final product.Furthermore, the technical value and the total quality (especially the mean length and the strength) of ecological cotton was less than the ordinary cotton fiber. For these reasons, the industrial exploitation of ecological cotton remained very limited.

Recovered cotton fibers were the waste of cotton that lost throughout spinning process. These kind of fibers were successfully used as alternative of virgin cotton fiber to produce blended yarn using several technologies such as Sirospun principle (11)(12), Open-End spinning (13,14) and ring spinning (15). Recycled cotton fiber was likewiseutilized to spin blended yarn and to substitute virgin cotton. This fiber was reclaimed after mechanical recycling of cotton waste like woven cloth and yarn waste(16). But the use of

recycled fiber in spinning yarn does not exceed 30%.According to Telli A. et al (17), This fiber used recycled cotton fiber obtained from cotton yarn waste to spun blended yarn. In this study, the yarn obtained in optimum conditions contains 25% of recycled fiber.In a similar study by Halimi M. T. et al (18) the same fiber was used from recycled cotton waste to produce Open-End yarn. The ratio of recycled fibers in obtained yarn does not exceed more than 25%. The use of small amount of recycled fiber in previousworks was due to the lack ofanalysis and optimization studies of recycled fibers quality.

This study aims to optimize the quality of recycled cotton fiber as an alternative of virgin fibers. Global quality indexes were used in order to evaluate the total quality of obtained materials. Mathematical approach was investigated to analyze the characteristics of the combination of recycled fibers with virgin cotton from several countries of origin. The idea was to give an optimal alternative for virgin cotton to spin sustainable DENIM yarn with high ratio of recycled fibers.

2. Material and Method

2.1. Materials

In this study, recycled fibers were reclaimed after waste yarn recycling process. Malian, Greek and Brazilian cotton was selected to mix with recycled fiber since they were known for their good length feature. Table.1 shows the physical and mechanical characteristics of recycled Malian,Greek and Brazilian as virgin cotton fibers. The mix preparation process was shown in Figure 1. The fibers tuft samples were selected randomly and tested for their characteristics after conditioning in standard atmosphere for 48 h.

2.2. Recycling process

In this study, the waste of yarn was collected from Spinning Company (SITEX) from Tunisia. Recycling process was performed with AMP7 DELL'ORCO machine. The recycling machine consists of a large breaker and six workers with saw teeth. The fraying of the fibers takes place gradually from one worker to another.

2.3. Fiber analysis

Several samples were taken after each fraying passages and submitted for fiber analysis. During this study, both instruments Uster AFIS and Uster HVI were investigated.

Uster AFIS measurement was carried out with ten replications of 3000 individual fibers to determine Mean Length (ML), Short Fiber Content (SFC), Neps count (Neps), Span Length$SL_{2,5}$% and fineness. Uster HVI measurement was carried out with five replications to evaluate the tenacity (Str), Upper Half Mean Length (UHML), Upper Quality Length (UQL),Uniformity Index (UI), Micronary (MIC) and the grade (Rd and +b) of tuft of recycled cotton fibers.

2.4. Total quality of fiber

The recycled fiber quality was evaluated using two fiber quality index such as Fiber Quality Index (FQI) and Spinning Consistency Index (SCI). The reason to attribute a quality index to recycled fiber was to evaluate its suitability and to combine several quality criteria of fiber in one overall quality index.
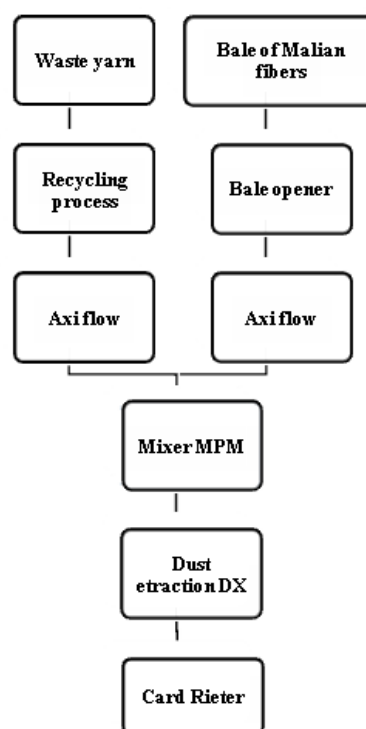

Figure 1. Mix line process

FQI have been related fiber strength, mean length and fineness (19) and defined by the following relationship:

$$FQI = \frac{ML \times Str}{Fineness}$$

Where ML was the mean length in mm, Str was the tenacity in cN/Tex.

Table 1. Characteristics of recycled and virgin fibers

Parameters	Brazilian fibers	Greek fibers	Malian fibers	Recycled fibers
Neps (Cnt/g)	34	105	66	189
Mean Length (mm)	23.2	25	26.1	19.6
Short Fiber Content (%)	5.1	6.8	6.2	20.6
Linear Density (mTex)	156	163	151	146
Strength (cN/Tex)	27.3	28.8	30.2	26.3
Fiber Quality Index	435	478	522	353.1

SCI was calculated to evaluate the spinnability of cotton fiber according to its properties (20). The regression equation of used to determine SCI was as follow:

$$SCI = -414.67 + 2.9Str + 49.1UHML + 4.74UI - 9.32MIC + 0.95Rd + 0.36b$$

Where Str was the tenacity in cN/Tex, UHML was the upper half mean length, UI was the uniformity index, MIC was the micronary index, Rd and b were the grade of recycled fiber.

2.5. Blending process

The two components of mixture were extracted from a laboratory sample which was obtained according to the sampling method NFG 07-062. This method can be summarized in two main steps. The first step is to extend each proportion of cotton into a regular sheet and to take the sample of material by randomly selecting in the sheet a minimum of 100 tufts, each from 0.25 g to 0.50 g. The method adopted for making a homogeneous mixture of 20 g of recycled cotton fiber with thespecific weight of virgin cotton was composed by ten steps as illustrated in Figure 2.
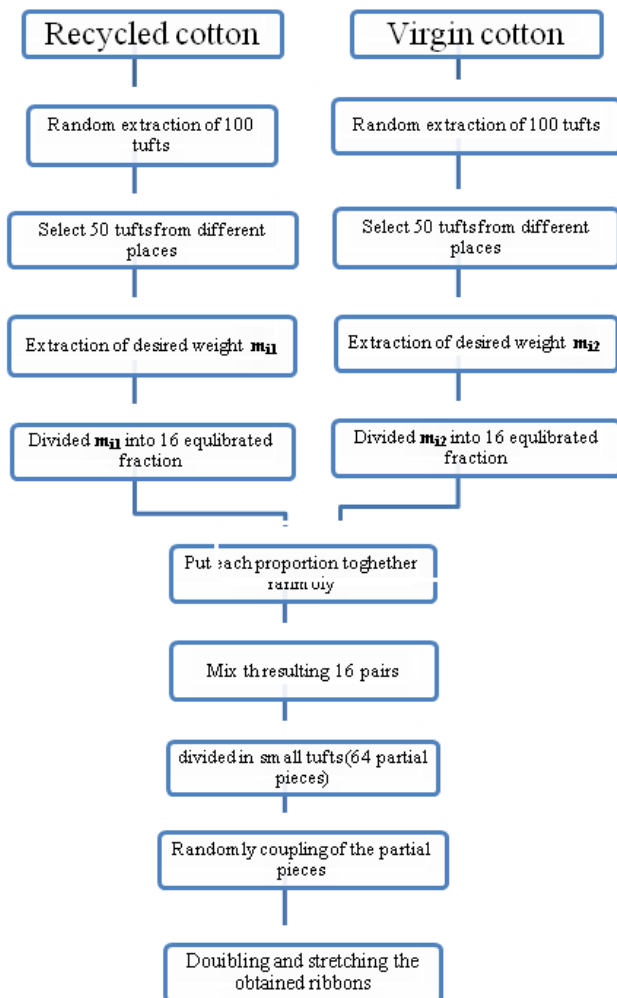

Figure 2. Blending process

2.6. Mathematical approach

In order to predict the properties of blended cotton fibers a mathematical approach was developed. The distribution function was shown as follow:

$$f(l) = \begin{cases} x\dfrac{w_{11}}{c} + (1-x)\dfrac{w_{21}}{c} & si \quad l \in [0,c] \\ \vdots \\ x\dfrac{w_{1i}}{c} + (1-x)\dfrac{w_{2i}}{c} & si \quad l \in [(i-1)c, ic] \\ \vdots \\ x\dfrac{w_{1n}}{c} + (1-x)\dfrac{w_{2n}}{c} & si \quad l \in [(n-1)c, nc] \\ 0 & si \quad l \geq nc \end{cases}$$

Where 'x' was the blending proportion, w_{1i} was the fraction of recycled fibers in the length range of $[(i-1)c, ic]$ and w_{2i} was the fraction of virgin cotton fibers in the length range $[(i-1)c, ic]$.

For two categories of cotton (Cotton1 and Cotton2) with normal fiber length distributions and with mean lengths ML1 and ML2, the distribution f of a binary blend constituted from these two cottons with the proportions x and (1-x) are calculated by applying the following formulas:

F= xf₁ + (1-x)f₂

2.7. Yarns Spinning and testing

The rotor spinning process of recycled fibers with Malian fibers was composed of several steps. Firstly, the bales of virgin Malian fibers and recycled fibers (with the appropriate proportion of blends) were opened with the Bale Opener machine. Secondly, the mixer storage Unit (MPM, with eight rooms) was used to improve the homogeneity of blends fibers. Thirdly, the homogeneity and regularity improved successively by means of Reiter card and Draw frame machines. Finally, Schlafhorst Autocoro rotor spinning machine was investigated to produce Ne 20 bended yarns.

Mechanical and physical properties of blended yarns were measured under standard humidity and temperature conditions by means of high-speed tensile Uster[®] Tensojet and USTER TESTER 5-S800 instrument, respectively.

3. Results and discussions

3.1. Reclaimed Fiber quality

After fraying of yarn waste, the recovered material was a mix between bits of yarns and recycled cotton fibers. The fraying efficiency (Y %) is the mass fraction of fibers in the recovered material (Figure 3.). According to Figure 4 it can be seen that the increasing on the number of passages of yarn waste on can effectively improve the fraying efficiency. This was explained by the transformation of bits of yarn that contained on reclaimed materials into fibers after each passage with recycling machine. It should be noted that beyond five passages it have been a slight increase of fraying efficiency. This was due to the decreased on the length of yarn bits after five passages.
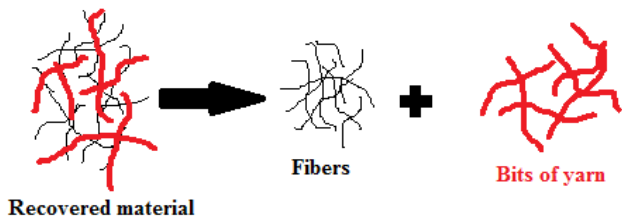
Figure 3. Recovered materials

39.4 mm to 35.1 mm after the first and the fore passage, respectively. Nevertheless, it can be seen that there is no significant effect of passage numbers on the UHML and the uniformity index (UI). Which means that the effect of this parameter was mainly concerns the short fibers distribution.

Passages number	Neps	SFC	ML	UHML	UI
	Cnt/g	%	mm	mm	%
1	213	17.6	15.3	22.9	64.9
2	206	19.2	14.6	23.2	64.6
3	191	20.1	14.9	23.0	64
4	189	20.6	14.9	22.6	63.8
5	194	21.3	14.2	22.,4	63.8
6	180	21.3	14.6	22.4	62.6
7	230	21.1	14.4	22.8	64.5

Both FQI and SCI as composite quality index were investigated in order to evaluate the effect of passages number on the technological value of recycled cotton fibers (Figure 6). It can be seen that when the passages number increase from 1 to 7, the FQI increase from 262 to 278. Although, there has been a decrease of SCI from 835 to 799, it can be concluded that, if we consider the finesses, the tenacity and the mean length as main criteria of recycled fiber quality, it can be said there was an improvement of the total quality of reclaimed fibers as well as the increase in the number of passages. However, it has been an opposite behavior on the relation with SCI as quality index. Indeed, when the passages number increase the SCI quality index decrease. As compared with FQI, previously interpreted, it can be concluded that if the grade, the Micronary index and the uniformity index were considered as the quality criteria of reclaimed fiber, the passages number show a decrease on the total quality of reclaimed fibers.
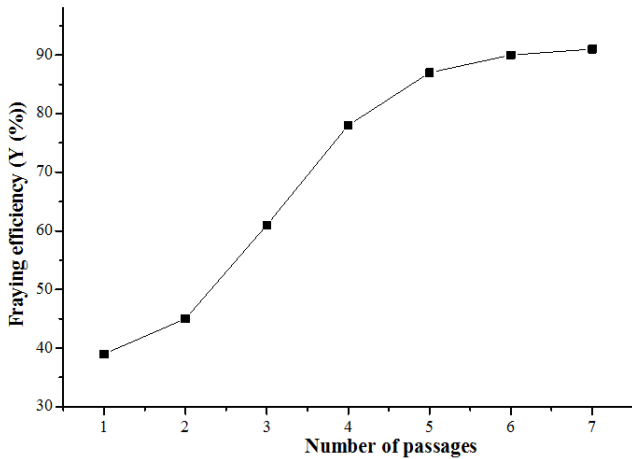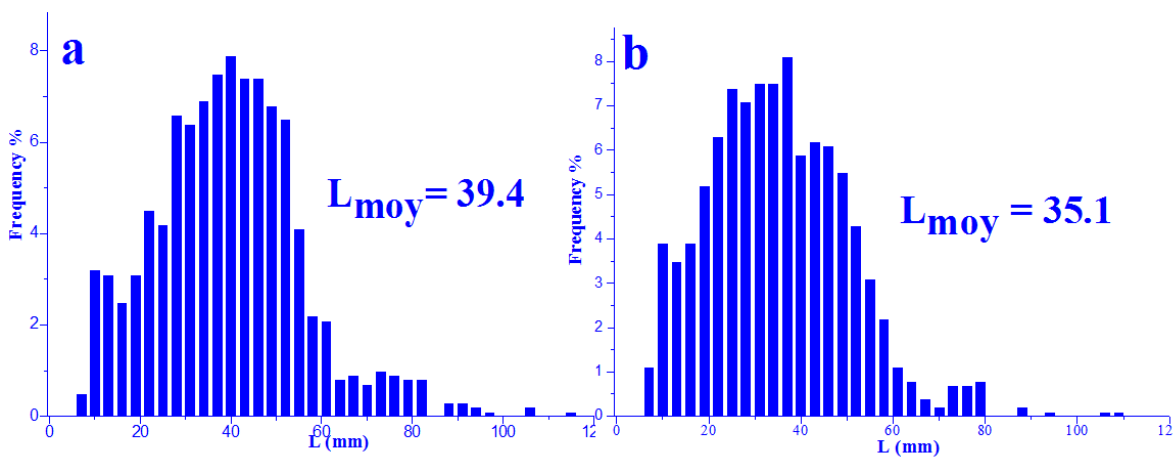

Figure 4. Effect of number of passages on the fraying efficiency

On the other hand, the number of passages had a significant effect on the quality of reclaimed fibers (Table.2).Indeed, there was an increase of Neps count and the ratio of short fibers (SFC). Due to the increase of the number of passage, the solicitation on the fibers increases. The mean length of reclaimed fibers decreases from 15.3 mm to 14.4 mm after seven passages which due essentially to the decreasing of the length of bits of yarns that generates those fibers(Figure 3.). In fact, as illustrated in Figure 5, the average value of bits of yarns decrease from

Figure 5. Length distribution of bits yarns. a: After the first passage, b:after fore passages
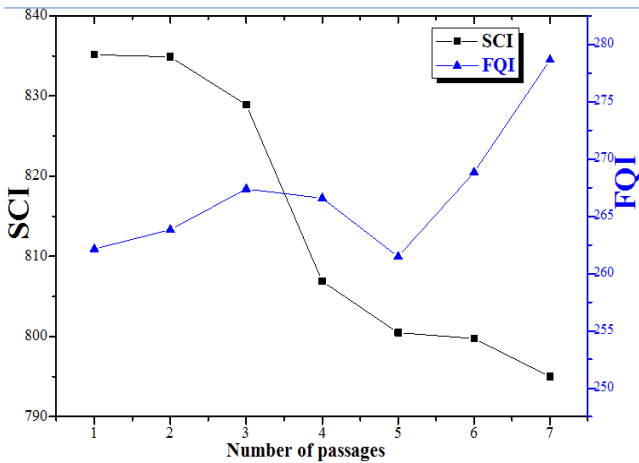
Figure 6. Effect of passages numbers on FQI and SCI index

Face with this behaviors and in order to select the optimum quality of reclaimed fiber, we have to consider the intersection point of FQI and SCI plot as the optimum total quality of reclaimed fiber. It can be concluded that the optimum total quality of recycled fiber was achieved through four passages of yarn waste where the FQI was 267 and the SCI was 806. In order to give more objective judgment to the recycled cotton fibers obtained in optimum condition, an international classification was investigated. This classification was defined by the Center for International Cooperation in Agronomic Research for Development (CIRAD)(21).This method involves the split of each quality parameter of cotton fiber into several ranges and gives an objective assessment for each.

It can be seen that, in the optimum conditions, recycled cotton fiber was considered as short silk, very irregular, very fine and resistant from mean length, uniformity index, fineness and strength respectively (Table 3). It can be concluded therefore that the recycled fiber was not suitable for spinning and its poor quality characteristics can give several problems during spinning process. For this reason, the recycled fiber should be blended with virgin cotton fiber in order to improve the global fiber quality.

Table 3. Quality value of recycled fibers

Parameters	Value	CIRAD Classification
ML (mm)	19.6	Short silk
UI (%)	63.8	Very irregular
Fineness (mTex)	146	Very fine
Str (cN/Tex)	26.3	Resistant

3.2. Quality of blends fibers

As indicated earlier, a mathematic approach was investigated to analyze the quality of blends. The main goal of this method is to evaluate the quality parameters of the mix of recycled cotton with three virgin cotton fibers such as Malian, Greek and Brazilian fibers. The ML, UHML, SL$_{2.5}$, UQL, Fineness, UR and CV were evaluated.

As shown in Figure 7, it can be seen that the evolutions of quality parameters of blended cotton fiber (Recycled/Virgin

cotton) as function of blended ratio 'X'. It is remarked that there is a linear evolution of ML, UHML and UQL as function of blended ratio which exhibit a proportional relation between those parameters and the blended ratio. It is remarked, also, that the mix of recycled fiber with Malian cotton as virgin fiber shows the highest predict value of ML, UHML, SL$_{2.5}$ for each blended ratio. But it has been an opposite behavior of Fineness, UR and CV parameters which mean the mix of recycled fibers with Malian fibers give fine and regular mix. Consequently, the mix of recycled cotton and Malian fibers as virgin cotton gives, in each blended ratio, the best quality and the better regularity according to the mathematical approach.
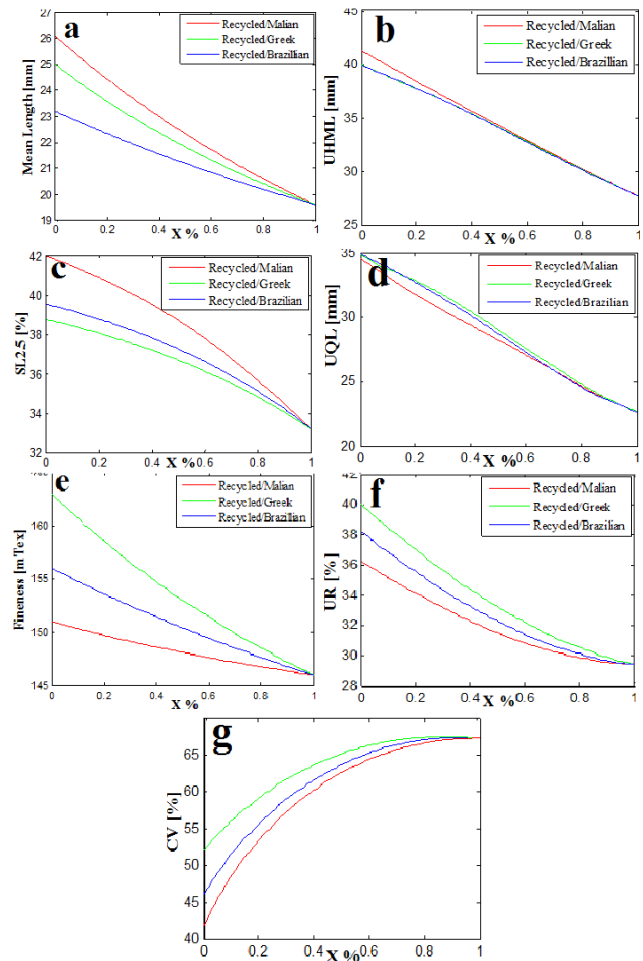

Figure 7. Effect of blended ratio on the mix fiber quality. a: effect on ML, b: effect on

The mix of recycled fiber with several blended ratio such as: 0%, 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90% and 100% were evaluated. R² as regression coefficient was used to evaluate the correlation between mathematical and experimental results. As summarized in Table 4, it can be seen that the value of R² was near to unit, which indicate that there is a good correlation between the experimental and mathematical results. The highest value of R² was obtained for the ML measurement which exhibits a good correlation between experimental and mathematical value.

This result indicates that the mathematical approach is reliable, on the one hand, and on the other hand it is attributed to the fact of it as a direct measure of mean length parameter. The lowest value of the regression coefficient corresponds to the UR and CV parameters because both CV and UR parameters presents a combination of several parameters.

Table 4. Regression coefficient of blended fibers

Quality parameter	Malian	Greek	Brazilian
ML [mm]	0.97	0.96	0.96
UHML [mm]	0.93	0.91	0.90
SL$_{2,5}$ [%]	0.97	0.95	0.94
UQL [mm]	0.95	0.92	0.93
Fineness [mTex]	0.94	0.93	0.92
UR [%]	0.81	0.78	0.79
CV$_m$ [%]	0.82	0.81	0.79

According to both experimental and mathematical approaches, the mix of recycled fiber and Malian cotton give the best qualities parameters.

It can be concluded therefore that there is good agreement between mathematical and experimental results which confirmed that the mathematical approach can be considered as efficient method to predict several parameters of blends cotton fibers such like ML, UHML, UQL, etc. That is, for each blends ratio, it can predict the quality parameter using this mathematical approach without going through experimental tests.

3.3. Yarns results

A summary of blended yarns results obtained is given in Table 5, which shows the mean values yarns irregularity such as the weight variation, thinness, thickness, the number of Neps per kilometer and the hairiness related to the blended ratio. According to this table, it can be seen that where the ratio of recycled fiber increase in the yarn, the imperfection parameters increase. Indeed, if the recycled fibers ratio in the blended yarn, increase from 40% to 75% the weight variation, thinness, thickness, the number of Neps per kilometer and the hairiness increase 20%, 13%, 32%, 50% and 20% respectively.

Table 5. Imperfection of blended yarn

Malian Proportion (%)	60	50	40	25
Recycled Proportion (%)	40	50	60	75
CVm (%)	11.9	12.5	13.1	14.3
Thinness 30%/Km	754	801	823	855
Thickness 30%/Km	235	257	298	311
Neps 280%/Km	2	2	2	3
H(%)	5	5.1	5.3	6

The increasing value of blended yarn irregularity is probably due to the correlation between fibers parameters and yarns imperfections. As shown previously, the global quality of recycled fibers was less than of Malian fibers. Therefore, if the proportion of recycled fibers increase in blended yarns, its irregularity increases. Although, it is well known today, that this kind of yarns (withrandom irregularities) are required for some particular application such as like the DENIM tissue with Ring effect.

It can be seen in Figure 7 that if the blended ratio of recycled fibers increase in the obtained yarn, its tenacity decrease. If the blended ratio increases from 40% to 75%, the tenacity of blended yarn decreases by 16%. Recycled fiber was considered, relatively, as short fiber. Therefore, if its ratio increases in blended yarn, the cohesion inter-fiber decreases. This can decrease the tensile strength of obtained yarn. This blended yarn can be used for specific application with low solicitation like a weft of DENIM woven. This can give a suitable appearance to DENIM woven, mainly, after washing treatement.

4.Conclusion

The effect of recycling process on the quality behaviors of reclaimed fiber was investigated with the aim of improving its global quality and expending its range of application. It is believed that increasing the passage number decrease the most of fiber quality parameters. But the uses of SCI and FQI as global quality index have given a compromise between the yield and the total quality of reclaimed fibers.

The use of mathematical approach to simulate the quality behavior of the mix of recycled fiber with virgin cotton fiber show that blend with Malian cotton give the most suitable fiber quality for efficient application. Mathematical simulation of ML, UQL, UHML and Fineness shows good agreement with experimental results according to R² as regression coefficient (0.97, 0.95, 0.93 and 0.94 respectively). It can be concluded that, firstly, recycling process of cotton waste with fore passages numbers gives an optimal global quality of reclaimed fibers. Secondly, the mix of recycled fibers with Malian cotton was beneficial to do low-cost sustainable product. An investigation was carried out on the effect of recycled cotton ratio on the irregularity and tenacity of blended yarn. The results demonstrated the thin place, thick place, Neps and unevenness of blended yarn increase with the increasing ratio of recycled fibers in the yarn. The use of recycling cotton as ecological and low-coast fibers can be benefit for special application like a weft of DENIM tissue.

REFERENCES

1. Güngör A, Palamutçu S, İkiz Y. 2009, COTTON TEXTILES AND THE ENVIRONMENT: LIFE CYCLE ASSESSMENT OF A BATHROBE. TEKSTİL VE KONFEKSİYON.;19(3), pp:197–205.

2. USDA | Commodity Forecasts | World Agricultural Supply and Demand Estimates. Interagency Commodity Estimates Committee Forecasts; 2017.

3. Thouvenot T. 2012, The Water Footprint of France. Vol. 56. PaysBas: University of Twente, pp; 1-38.

4. Agbohessi PT, Toko II, Atchou V, Tonato R, Mandiki SNM, Kestemont P. 2015, Pesticides used in cotton production affect reproductive development, endocrine regulation, liver status and offspring fitness in African catfish Clarias gariepinus (Burchell, 1822). Comparative Biochemistry and Physiology Part C: Toxicology & Pharmacology.;167, pp;157–72.

5. Aral N, Berkalp ÖB, Bakkal M, Sadikoğlu TG. 2009, INVESTIGATION OF IMPACT AND TENSILE BEHAVIOURS OF WASTE FABRIC REINFORCED POLYMER COMPOSITES. TEKSTİL VE KONFEKSİYON.;19(2), pp:139–44.

6. Taşdemir M, Koçak D, Merdan N, Usta İ, Akalin M. 2014, Recycled Polyamide-6/Waste Silk & Cotton Fibre Polymer Composites:Effect of Fibre length. Marmara Fen Bilimleri Dergisi.;25(4), pp:157–66.

7. Gülümser T, Balpetek FG, Demir A. 2015, DURABILITY OF FABRIC SOFTENERSR17; ODORS USED IN HOME TYPE OF WASHINGS AT COTTON PRODUCTS DURING WEARING. TEKSTİL VE KONFEKSİYON.;25(3), pp:263–9.

8. Telli A, Babaarslan O. 2016, COMMERCIALIZED DENIM FABRIC PRODUCTION WITH POST-INDUSTRIAL AND POST-CONSUMER WASTES. TEKSTİL VE KONFEKSİYON.;26(2), pp:213–20.

9. Natalio F, Tahir MN, Friedrich N, Köck M, Fritz-Popovski G, Paris O. 2016, Structural analysis of Gossypium hirsutum fibers grown under greenhouse and hydroponic conditions. Journal of Structural Biology.;194(3), pp:292–302.

10. Regina A. Sanches, João Paulo Pereira Marcicano, Maria Silvia Barros de Held, Bárbara Maria Gama Guimarães, Raquel Seawright Alonso, Karina Mitie Takamune ,2015, Organic cotton, lyocell and SPF: a comparative study. Int Jnl of Clothing Sci & Tech.;27(5), pp:692–704.

11. Hanafy I. 1997, Fabric from cotton waste. Ihe Indian Textile Journal.;4(3), pp:16–8.

12. M.N. Sun, K.P.S. Cheng. 2000, The quality of fabric knitted from cotton Sirospun1 yarn. Int Jnl of Clothing Sci & Tech.;12(5), pp:351–60.

13. Halimi TM, Azzouz B, Ben Hassen M, Sakli F. 2009, Influence of Spinning Parameters and Recovered Fibers from Cotton Waste on the Uniformity and Hairiness of Rotor Spun Yarn. Journal of Engineered Fibers and Fabrics.4(3), pp:36–45.

14. Bruggeman JP. 1998, Traitements mécaniques des déchets et des cotons charges. Industrie textile.;11(28), pp:1049–51.

15. Wulfhorst B. 1984, The technological and economic aspects of the recycling of wastes in modern cotton mills. Textile Praxis International.;1(1), pp:741–3.

16. Wanassi B, Azzouz B, Hassen MB. 2016, Value-added waste cotton yarn: Optimization of recycling process and spinning of reclaimed fibers. Industrial Crops and Products.;87, pp:27–32.

17. Telli A, Babaarslan O. 2017, The effect of recycled fibers on the washing performance of denim fabrics. The Journal of The Textile Institute.;108(5), pp:812–20.

18. Halimi MT, Hassen MB, Azzouz B, Sakli F. 2007, Effect of cotton waste and spinning parameters on rotor yarn quality. The Journal of The Textile Institute.;98(5), pp:437–42.

19. Majundar A, Majundar PK, Sarkar B. 2005, DETERMINATION OF THE TECHNOLOGICAL VALUE OF COTTON FIBRE: A COMPARATIVE STUDY OF THE TRADITIONAL AND MULTIPLE-CRITERIA DECISION-MAKING APPROACHES. AUTEX Research Journal.;5(2), pp:71–80.

20. Asif M, Mirza JI, Zafar Y. 2008, GENETIC ANALYSIS FOR FIBER QUALITY TRAITS OF SOME COTTON GENOTYPES. Pakistan Journal of Botanic.;40(3), pp:1209–15.

21. Dochia M, Sirghie C, Kozłowski RM, Roskwitalski Z. 2012, Cotton fibres. Handbook of Natural Fibres. vol. 1, pp; 11–23.