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RESEARCH ARTICLE

Recycling of post-industrial cotton wastes: Quality and rotor spinning of reclaimed fibers

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Abstract

Mechanical recycling of post-industrial cotton yarn wastes, as well as the effects of passage number on the properties of reclaimed fibers, has been investigated. A new Modified Fiber Quality Index (MFQI) and Spinning Consistency Index (MSCI) for the characterization of the quality are presented. This index gives the real potential of spinnability according to its physical properties. The best quality of reclaimed fibers (after 7^{th} passage) was used to produce a rotor yarns. 100% recycling cotton yarns were produced in open-end spinning system with different rotor speed (i.e. 65000, 70000 and 80000 rpm), opening roller speed (i.e. 7700, 8200 and 8700 rpm) and twist factor (i.e. 137, 165 and 183). The effects of spinning parameters were investigated to evaluate a 100% recycling cotton yarns quality (TQI, hairiness, thin places and thick places) using DOE method.

Introduction

The growing awareness of environment and economic conscience of manufacturers and consumers are constantly increasing worldwide. They are all motivated and ambitious to recycle wastes and to purchase recycled products. Thus, recycling can be defined as the handling process of used material so that they can be used again **(Larney. M. 2010)**. The recycling of waste provides great energy and water conservation a magic word for a sustainable life in the world **(Tarakçıoğlu. I, 2008)**. Recycling industry must be economically competitive and environmentally beneficial **(Wang. Y, 2006)**
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Textile industries produce an enormous quantity of waste. Unfortunately, recycling practices in this field are not satisfactory. In the last decade, enormous efforts in developed countries to promote recycled products and encourage consumers to use this type of product **(Güngör. A, 2009).**

Many studies carried out to study the waste potential and the energy usage and environmental effects of each stage of recycling process **(Gam. J.H. and Banning. J. 2011)(Swinker. M.E.and Hines, J.D., 1997)**.

Determining the technological value of cotton fiber is an interesting field of textile research.

Many research studies have been conducts to observe the phenomenon of spun yarn failure which is found to be strongly dependent on yarn structure, fiber packing in the yarn cross section**(Frydrych. I, 1995)(Ghosh. A, 2005)** as well as the cellulose accumulation inside the cotton fibers**(Shu. H, 2007)**.

Several studies have been published and different formulas are suggested to define the cotton fiber quality (**Militky. J,2012)(Suh. MW and Sasser, 1996)(Majundar. A, 2005)**. Militky and Kremenakova (2012) described that the procedure for the evaluation of cotton quality index can be simply modified for other selected properties or other set of weights. Considering different fiber properties and assuming linear geometric properties, some criteria based on the regression models connecting fiber properties with parameters are used to characterize spinning ability or quality of yarn **(Asif. M, 2008)**.

From the literature, many research studies are interested to spinning recycling fibers or waste of cotton fibers. Halimi et al are studies the effect of rotor spinning parameter and the rate of waste cotton in blended yarns quality.

This studies show that using a rate of 25% of waste cotton on rotor blended yarn without changing the quality of yarn**(Halimi. T.M,2007)(Halimi. M.T, 2009).**

Hossin. H and Zeyedi.T **(HOSSEIN. H, 2010)** studied the effect of rotor parameters, naval speed, opener speed, separator type and yarn linear density on the yarn quality from different ginning waste proportion (65%, 50%, 35%) using Taguchi method. Two spinning parameters shows a dominant effect on the quality index of the yarn for each rate of waste. These parameters are yarn linear density and rotor parameters. That confirm a studies of Hanafy .I on 1997**(Hanafy. I, 1997)**.

Özlem K.N et al were studies the usability of recycled garments which were manufactured by evaluating fabric scraps. 50%-50% recycled cotton-Polyester yarns were produced. The physical properties of yarns, fabrics and garments were compared with products that made from virgin materials. The test results indicated that there is not a distinctive difference between recycled and virgin garments qualities. As the result of this study, it can be stated that recycled garments produced from fabric scraps can be used in apparel manufacturing industry**(Kurtoglu. N, 2013)**.

The aim of this paper is to evaluate the quality of mechanical recycling fiber and study the spinning potential of reclaimed fibers. For this purpose, 100% recycling cotton yarns was produced with different spinning parameters.

2. Materials and Methods

2.1. Waste yarns treatment

The waste of yarn was collected from SITEX spanning company. This waste is formed by chunks of yarns including defects detected and removed by winding machine. To recycle this waste, a machine which include a breaker with sawteeth, was used.

2.2 Fibers analyses

USTER HVI and USTER AFIS, were used for the duration of this study to fiber analyses. Table1 contains summarized fiber analysis results. In order to ensure the raw fiber properties measurements were representatives, each specimen was taken randomly.

Fiber quality index (FQI)

To determine the technological value of cotton fiber, the FQI is the most widely method used (**Sreenivasa. M, 2000)**.

The main reason behind its popularity may be attributed to the simplicity of the equation used. Many variants of FQI model are available. In this work we have used two forms of FQI: FQI_{hvi} and $MFQI_{hvi}$ which is respectively HVI quality index and modify HVI quality index.

$$\mathbf{FQI_{hvi} = \frac{UHML.UI.STR}{MIC}} \quad (1)$$

$$\mathbf{MFQI_{hvi} = R.FQI_{hvi} = R.\frac{UHML.UI.STR}{MIC}} \quad (2)$$

Where FQI_{hvi} is HVI fiber quality index, UHML is upper half mean length, UI is uniformity index, STR is strength and MIC is micronaire.

$MFQI_{hvi}$ is modifying HVI fiber quality index and R is recycling efficiency.

$$\mathbf{R = \frac{M_f}{M_f + M_y}} \quad (3)$$

Where R is recycling efficiency, M_f is the mass of fiber content in the mix after recycling waste yarn and M_y is the mass of parts content in the mix after recycling waste yarn.

Spinning consistency index (SCI)

It is a calculation for predicting the overall quality and spinnability of the cotton fiber. It is chiefly used to gain within and between lay-down consistencies of major cotton properties. The regression equation of SCI uses most of the individual HVI measurement and it is based on five-year crop average of U.S Upland and Pima cotton. The regression equation used to calculate SCI **(Zellweger Uster, 1999)** is as follows:

$$\mathbf{SCI = -414.67 + 2.9\,FS + 49.17\,UHML + 4.74\,UI - 9.32\,FF + 0.65Rd + 0.36(+b)} \quad (4)$$

Where Rd is reflectance degree and +b is yellowness of cotton fiber.

Introducing recycling efficiency R, this index will be:

$$\mathbf{MSCI = R.\,SCI = R.(-414.67 + 2.9\,FS + 49.17\,UHML + 4.74\,UI - 9.32\,FF + 0.65Rd + 0.36(+b))} \quad (5)$$

In order to estimate the individual effects of each of the controllable factors on a particular response the method of experimental designs has been used in this study. The main effect plots and the analysis of variance were used for statistical analysis of the results. This analysis consists of calculating statistic parameters that indicate whether the factors are significantly related to the response data and each factor's relative importance: the mean sum of squares (MS), the F-statistic (F) and the p-value (P). The controllable factors, which were considered in this research, are opening roller speed (OR), rotor speed (RS) and twist factor (TF). We chose the orthogonal array L_{27} shown in table 1, it required twenty-seven runs for combinations of three controllable factors varied at three levels (Table 2). The yarns produced with the three opening roller speed, rotor speed and twist factor rotor diameters were tested for tenacity, elongation and evenness (hairiness, CV%, thin 30% and thick 30%). Samples were kept in standard testing condition for 24h prior to testing. Variations were to be expected within individual yarn bobbins, so the first few meters were discarded. For each yarns sample, we took ten specimens to obtain an average value.

The total yarn quality index (TQI) was the response in our study. This index was calculated using the following formula **(Barella. A, 1976)**:

TQI = Tenacity (cN/Tex) x Elongation(%)/CV% **(6)**

Table 1. Experimental design

Run	**OR**	**RS**	**TF**
1	8700	65000	137
2	8200	70000	165
3	7700	70000	165
4	8200	65000	183
5	8200	80000	137
6	7700	70000	137
7	8200	80000	165
8	7700	65000	137
9	8700	80000	165
10	8700	80000	183
11	8700	65000	165
12	8200	65000	137
13	8200	70000	183
14	7700	80000	183
15	7700	70000	183
16	8700	70000	183
17	7700	80000	137
18	7700	65000	165
19	8700	70000	165
20	8700	65000	183
21	7700	65000	183
22	8200	65000	165
23	8200	80000	183
24	8700	70000	137
25	7700	80000	165
26	8200	70000	137
27	8700	80000	137

Table 2. Factors levels

Run	**Opening roller speed rpm (OR)**	**Rotor speed rpm (RS)**	**Twist factor α (Tf)**
1	7700	65000	137
2	8200	70000	165
3	8700	80000	183

3. Results and discussions

3.1 Recycling Fiber

Recycling of waste yarns provides a flock, which is a mixture of fibers with pieces of cut yarns. After each pass of the material in the recycling machine, manual separation operation is carried out in order to select the fibers that are going to be testing on HVI and AFIS.

The MFQI and FQI given in the formula (2) and (3) is calculated for different passage number of recycling cotton and the results are given in Figure 1. The FIQ of recycling cotton fibers decreases with the number of passes, but from the 6th pass this index increases. This increase in this level is explained by the decrease of micronaire. The micronaire value, for a virgin cotton fiber is caused by genetic and environmental characteristics of the plant **(Michael. P, 20010)**. But in the case of this study, the variation of the micronaire value of the recycled fibers is caused by the mechanical stress along the unraveling cycle. Generally, when the micronaire decreases there will be a more damaged fiber.

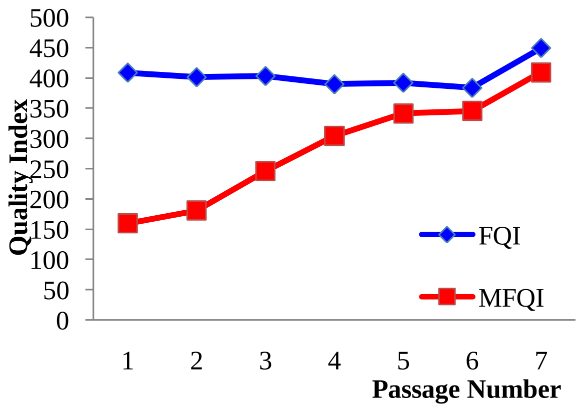

Figure 1. Variation of FQI and MFQI

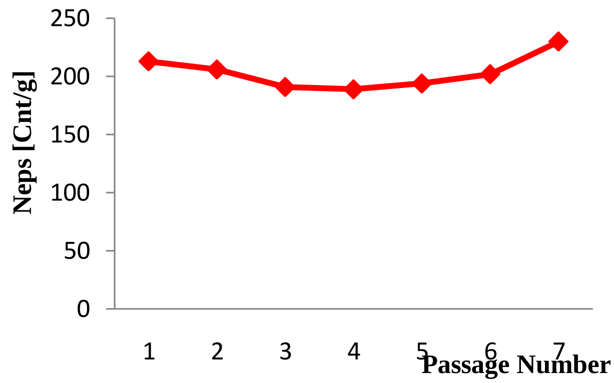

Figure 2. Variation of Count of Neps [Cnt/g]

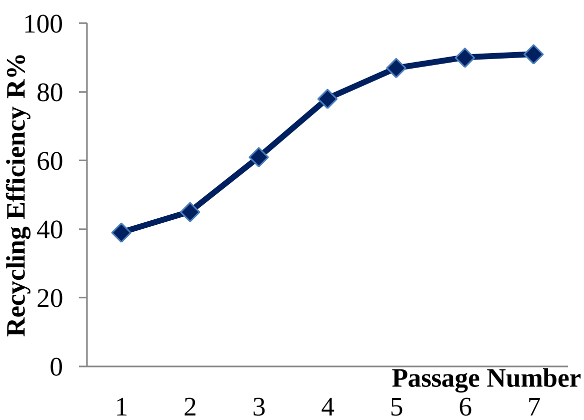

Figure 3. Variation of recycling efficiency R%

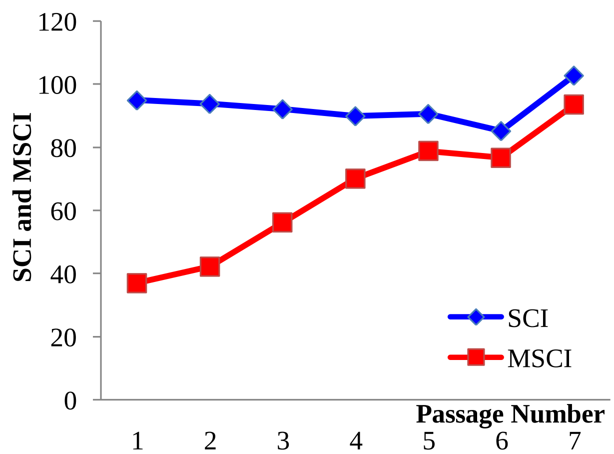

Figure 4. Variation of SCI and MSCI

The fibers with a lower micronaire are generally the most flexible fibers and tangles easier to form Neps (**Linghe. Z, 2010)**. This argument can be justified by the variation in the rate of Neps at the 7th passage (Figure 2). The deviation in the pattern of the curve illustrating the variation in the number FQI passage at the 7^{th} passing is explained by the variation of the parameters that make up the index.

In this study, we are before a special case of cotton fibers (fibers recovered from the recycling of waste yarn). We cannot refer only to FQI to evaluate the quality of the reclaimed fibers. However, the variation of the quality index weighted by recycling efficiency MFQI increases with the passage number. This increase is caused by the increased efficiency of recycling R% (Figure 3). So the best quality cotton, according to this quality index is cotton recovered after 7^{th} passage.

MFQI represent the differences between the behaviors of the different varieties of recycling fiber on spinning mills. The performance of recycling fiber after 7^{th} passage is found to be better than that of fiber after first passage during the different stages of the spinning process.

The evolution of SCI by the number of passage (Figure 4) is not very significant. Indeed, during the first pass SCI is 95 whereas after the 7th pass there will only an evolution of 8% to get a value of 103. MSCI variation is very significant. The MSCI increases by 167% compared to the quality of recycled fiber from the first passage to the 7^{th} passage.

3.2. Yarns characterization

The experimental results have been statistically evaluated by using the Design Expert analysis of variance (ANOVA). F test is used to treat the interaction between design variables such as rotor speed, opener speed and twist factor.

Figure 5 shows the effect of the spinning parameter on the total quality index of the yarns produced from recycling cotton fibers. The results reveal that the best yarn quality is achieved when the rotor speed is 65000rpm. Similar observations were made by other researchers **(Lord. G. L,1981)(Trommer. G, 1995)**. High speed of rotor gives a smaller number of wrapper fibers, as expected. The yarn strength, in general, increased with the number of wrapper fibers. It was found that the number of belts per unit length increased with relatively lower speed rotors.
The deterioration of yarn tenacity at higher rotor speeds could be attributed to the increased false twist. Rotor speed has also a deteriorating effect on yarn tensile properties. In general, yarn elongation at break decreases as the rotor speed is increased. It may be due to increase in the spinning tension, which causes a permanent strain in the yarn. In the other hand, increased rotor speed can lead to increased yarn irregularity. Lower rotor speed gives relatively larger elongation for a certain rotor diameter. For this reason, the rotor speed has a negative effect in total quality index.

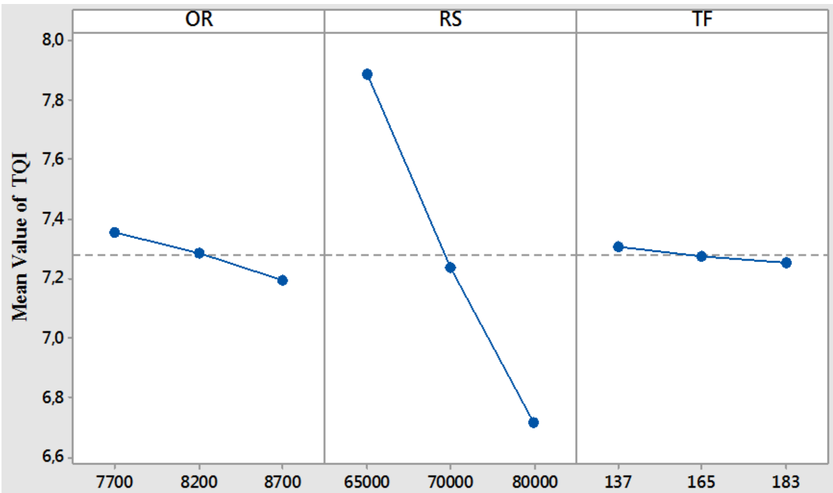

Figure 5. Main effect plot for TQI

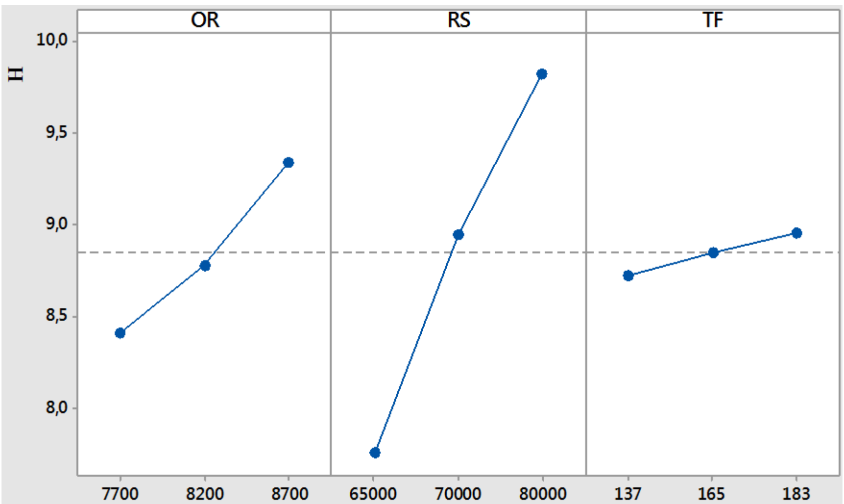

Figure 6. Main effect plot for H

An increase in opener speed can affect negatively the total quality index. As the opening roller speed increases, the carrying factor i.e. the effective number of wire points per unit time increases, which in turn increases the opening efficiency of the opening roller. Due to the better opening of fibers, it can be expected that the fiber tufts of smaller size and uniform dimensions are fed into the transport tube and thus into the rotor groove. But at the same time, too high an opening roller speed results in higher rotor deposition, and fiber orientation inside the transport tube also deteriorates drastically, which causes higher end breakage.

Therefore, in statistical analysis we have also considered the contributions of rotor speed, opener speed and twist factor to the variation in the response variables, as summarized in Table 3. The rotor speed explains 21% of the total variation TQI, whereas twist factor and opener speed alone are not an important factors, contributing to only 1.7% and 0.4% respectively, of the total variation. The F test provides us with similar results for TQI, indicating that rotor speed is significant, with a p-value of 0.000, and twist factor is insignificant with a p-value of 0.109.

Table 3. Analysis of Variance for TQI

Source	DF	SS	MS	F	P
OR	**2**	0.1210	0.0605	217.56	0.000
TF	**2**	0.0133	0.0066	23.86	0.109
RS	**2**	6.1741	3.0871	11098.66	0.000
Error	**20**	0.0056	0.0003		
Total	**26**	6.3140			

The figure 6 clearly illustrate that rotor speed is the most influential factor on the hairiness, and the effect of twist factor is very limited. Due to this fact, an F test for the significance of main factors (Table 4) show insignificant effect of twist factor.

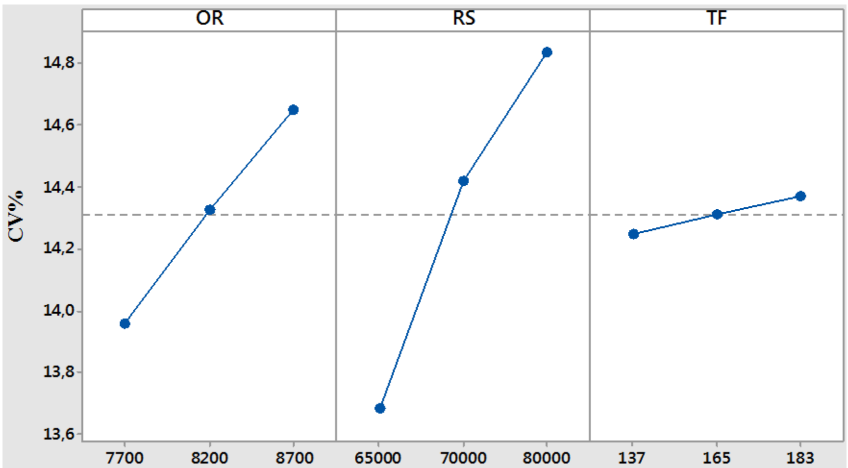

Figure 7. Main effect plot for CV%

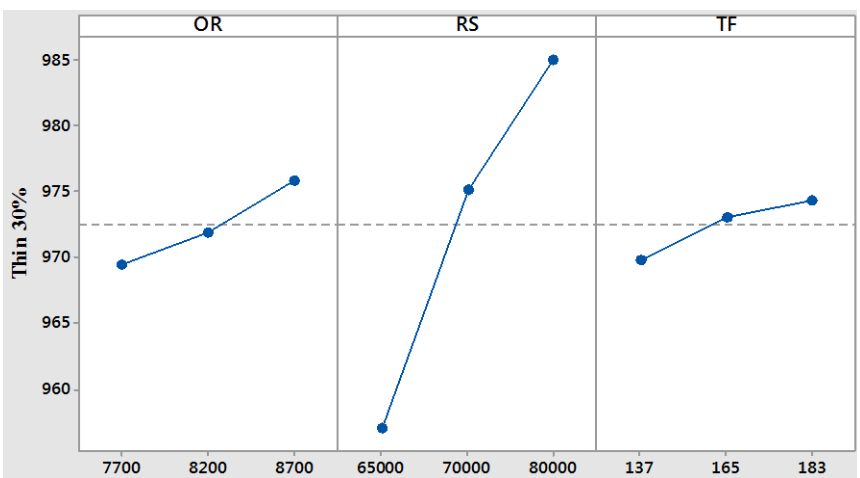

Figure 8. Main effect plot for Thin 30%

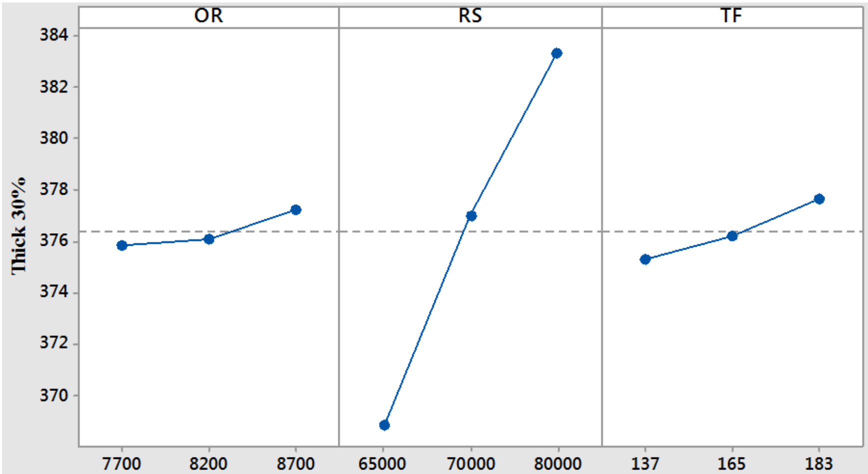

Figure 9. Main effect plot for Thick 30%

The hairiness of the yarn 100% recycling cotton has been found to be highly dependent on the rotor speed, as the greatest portion of variation (30.3%) (Figure 6). The contribution of opening roller speed to variation in hairiness is also, relatively, significant, with a 12% contribution (figure 6). According to table 4, rotor speed and opening roller speed have a significant effect ($p<0.1$) on the hairiness of yarn 100% recycling cotton. Whereas twist factor haven't a significant effect ($p = 0.137>0.1$) on the hairiness.

Table 4. Analysis of Variance for H

Source	DF	SS	MS	F	P
OR	**2**	3.9165	1.9582	35.43	0.000
TF	**2**	0.2431	0.1215	2.20	0.137
RS	**2**	19.3848	9.6924	175.35	0.000
Error	**20**	1.1055	0.0553		
Total	**26**	24.6499			

Table 5. Analysis of Variance for CV%

Source	DF	SS	MS	F	P
OR	**2**	2.1588	1.0794	20.32	0.000
TF	**2**	0.0673	0.0336	0.63	0.541
RS	**2**	6.1373	3.0686	57.77	0.000
Error	**20**	1.0624	0.0531		
Total	**26**	9.4258			

On the other hand, rotor speed and opening roller speed have a significant effect for, respectively, 9.2% and 5.4% of the total variation in yarn irregularity (CVm%) (figure 7). According to table 5, rotor speed and opening roller speed have a significant effect ($p<0.1$) on the CV% of yarn 100% recycling cotton. Whereas twist factor haven't a significant effect ($p = 0.541>0.1$) on the CV%.

Similar levels can be seen for the thin30% and thick30% places that determine the yarn imperfections. The rotor speed explains 3% of the total variation in thin places, whereas the opening roller speed explains 0.8% of the total variation (figure 8). The main effects of rotor speed and opening speed rotor on thick places are very limited, as indicated by the low contribution percentages of 4% and 0.5% respectively (figure 9). According p-value ($p=0.101$), twist factor haven't a significant effect on thin30% (Table6) and thick30% (table7). Rotor speed has a considerable effect on thin and thick place in 100% recycling cotton yarn. High speed of rotor affects negatively the yarn homogeneity.

Rotor speed seems to have a considerable effect on the thick places yarn. Working with high speed affects negatively the yarn homogeneity.

The variation of yarn irregularity (thin% and thick %) for both different factors: twist factor and opening roller speed was studies (figure 8 and figure 9). However, it may be noted that with the increasing rotor speed, the irregularity increase. This may be explained by the possibility that each time the peel-off point passes the exit of the fiber delivery tube; a bridging fiber will be wrapped around the body of the yarn. It is generally accepted that rotor-spun yarns are superior in terms of evenness to the equivalent ring spun-yarns, which is largely attributed to the doubling effect which takes place inside the rotor.

However, the presence of thin and thick is believed to contribute unfavorably to the measured yarn evenness, since a locally concentrated group of fibers on the yarn body will as such increase the mass per unit length in that section of the yarn **(Lord. P. R, 1974)(Nield. R, 1975)**. Although the configuration seems to be complex, increases in rotor speed in general lead to deterioration in yarn properties. The fiber individualization was lower for the high speed rotor, so that it is quite possible that the ring of fibers deposited in the groove of the smaller rotor experiences a greater false twist instead of real twist, thereby producing an irregular yarn **(Pirooz. F, 1981)**.

Table 6. Analysis of Variance for Thin30%

Source	DF	SS	MS	F	P
OR	**2**	184.67	92.33	20.77	0.000
TF	**2**	94.89	47.44	10.67	0.101
RS	**2**	3660.22	1830.11	411.77	0.000
Error	**20**	88.89	4.44		
Total	**26**	4028.67			

Table 7. Analysis of Variance for Thick30%

Source	DF	SS	MS	F	P
OR	**2**	9.19	4.59	0.89	0.425
TF	**2**	24.96	12.48	2.43	0.114
RS	**2**	943.63	471.81	91.85	0.000
Error	**20**	102.74	5.14		
Total	**26**	1080.52			

Conclusion

Results of this study indicate that after mechanical recycling of waste yarns, the best quality of reclaimed fibers is obtained after 7th passage according to the fiber quality index. The test results indicate that rotor speed had an important effect on 100% recycling cotton yarns properties statistically. Three parameters of the rotor spinning were varied to show their effects on 100% recycling cotton yarns. Using DoE methods, the effect of rotor speed parameters, twist factor and opening roller speed on the yarn quality was investigated. According to the level average analyses, rotor speed decrease significant TQI and increase the hairiness, thin30%, thick% and CV%. Twist factor haven't significant effects on quality of 100% recycling yarns.

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