Textile Technology

Harald Schwippl
Rieter Machine Works Ltd.
Winterthur, Switzerland

December 2020

The Increasing Importance of Recycling in the Staple-Fiber Spinning Process

Part 1

Contents

1. Increasing Importance of Recycling in the Textile Sector 4

2. Standards and Guidelines on the Market 5

3. Fiber Quality of Recycled Raw Material That Has Been Broken Down Mechanically 6

3.1. Degree of Fabric Opening 6

3.2. Efficiency of Fiber Opening from the Tearing Process 7

3.3. Fiber Length Characteristics 9

3.4. Requirements for Raw-Material Selection and Fiber Opening 12

4. Market Potential 13

5. Staple Fiber Spinning Process 14

6. Fiber Preparation 20

7. Yarn Quality for Ring Yarn 23

7.1. Unevenness 23

7.2. Neps 24

7.3. Tenacity and Elongation 25

7.4. Hairiness/Abrasion 27

7.5 Q-Package for Ring Spinning 28

8. Yarn Quality for Spin-Twist Yarn 29

9. Yarn Quality for Rotor Yarn Compared to Ring Yarn 31

9.1. Unevenness 31

9.2. Neps 33

9.3. Tenacity and Elongation 33

9.4. Hairiness and Abrasion 35

10. Fabrics 36
10.1. Pilling Performance 36
10.2. Optical Effect in the Fabric 37
10.3. Application 38
11. Process Recommendation 39
12. Economic Viability 41
13. Conclusion 43

1. Increasing Importance of Recycling in the Textile Sector

In recent years, better use of raw materials has become very important in the textile sector due to growing environmental awareness, legal requirements for more sustainability, and the cost of raw materials. Today, options for recycling do not just involve breaking down textiles mechanically, they also include chemical opening and using recycled textiles to produce new fibers.

Raw material that can be reused may be generated during the spinning process – this is called waste. This publication focuses on the raw material that occurs after the spinning process. Recycled material is collected either from pre-consumer steps or after a consumer has worn the clothes, so called post-consumer material.

Typical areas for the use of recycled raw material are the production of classic nonwoven and coarser rotor staple fiber yarns (Ne 5 – 10). Now the use of recycled raw material in downstream processing is being extended to the production of finer ring yarns with higher quality requirements.

A wide range of design ideas and growing consumer willingness to buy products made of recycled raw materials are increasing the demand. To meet this demand, the machine technology requires adjustment. In addition, intensive cooperation and coordination between the individual industrial sectors in the whole value chain is required. In order to shed some light on the ideal recycling process, Rieter has conducted a study on how to spin recycled post-consumer material blended with virgin cotton in various blends.

Definition of Textile Recycling – Example Cotton

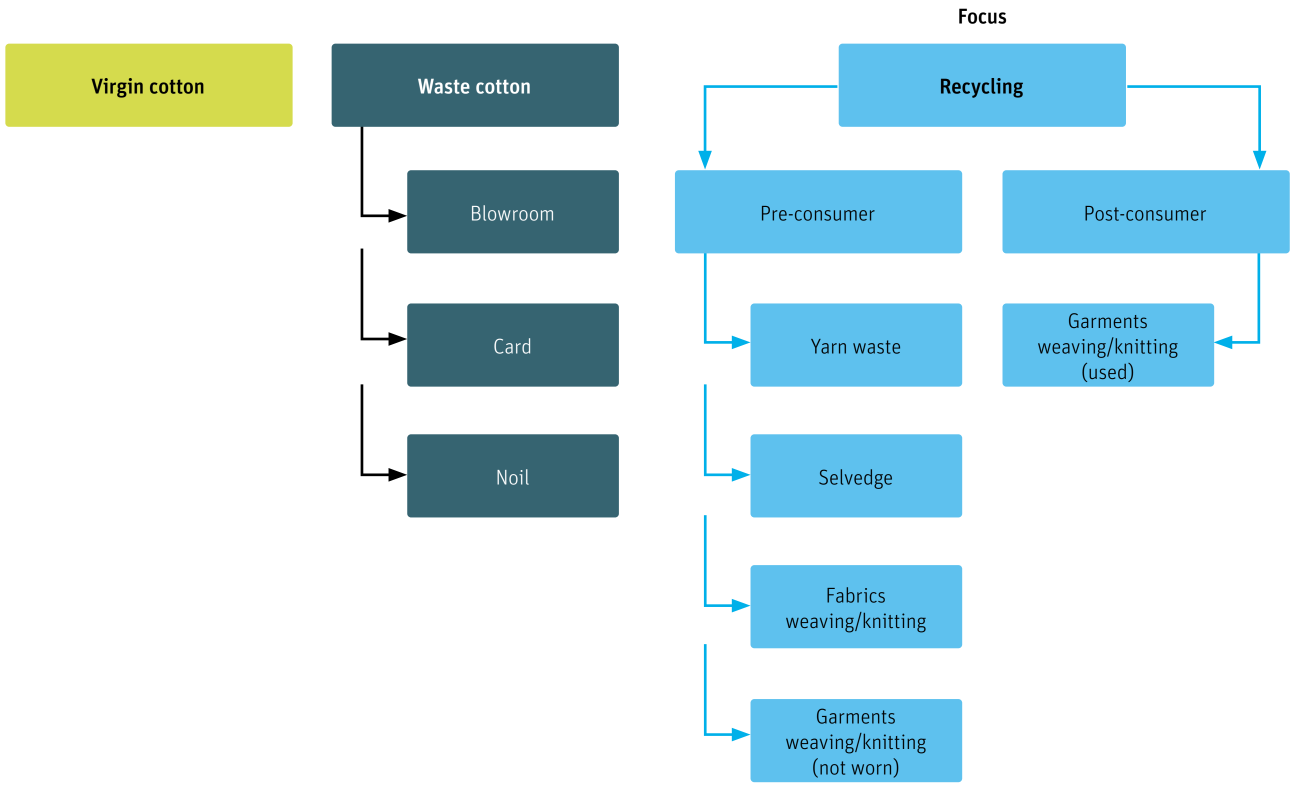


Fig. 1: Definition of Textile Recycling

Source: Technology & Process Analytics

2. Standards and Guidelines on the Market

There are already institutions that regulate fabric labeling to protect the end consumer when the product is marketed and commercially available. One important aim of these institutions is to promote the use of more recycled raw materials. This is possible if the quality requirements can also be satisfied technically, depending on the end product. The raw-material quality, yarn count, and using an appropriate end spinning process determine whether the requirements are satisfied in the end product.

For this reason, it is important that admixing virgin raw material does not create barriers to trade or uncertainty for the end consumer.

The Global Recycling Standard (GRS) applies to products containing at least 20% recycled material. The GRS is intended to meet the needs of companies looking to verify the recycled content of their (finished and intermediate) products and ensure that their production processes fulfill social, environmental, and chemical regulations. The GRS applies to companies involved in the ginning, spinning, weaving, knitting, dyeing, printing, and sewing processes.

There are a number of other institutions that also deal with standards and labeling for consumers and trade. These include:

- Content Claim Standard (CSS)
- Recycled Claim Standard (RCS)
- Certification Body (CB)
- Scope Certificate (SC)
- Transaction Certificate (TC)
- ISO/IEC: Rules for the structure and drafting of International Standards
- ISEAL: Code of Good Practice for setting social and environmental standards

3. Fiber Quality of Recycled Raw Material That Has Been Broken Down Mechanically

Preparing the raw material is crucial for the staple-fiber spinning process. This is a particular challenge and therefore important for post-consumer material. The degree of opening of the fabric contents and the efficiency determine how many fibers are already optimally prepared for the spinning process. To measure this, two key figures have been defined to describe the quality of the opening work.

3.1. Degree of Fabric Opening

In the current trial, the number of “non-open” fabric pieces remaining in the raw material after the tearing process was 7 to 8% of the total mass.

The degree of opening of the respective tearing process has therefore been defined as follows:

$$\text{Degree fabric opening DFO [\%]} = \frac{\text{fabric input} - \text{fabric output}}{\text{fabric input}} \times 100$$

If the percentage of remaining fabric pieces is 7.7%, the degree of fabric opening (DFO) would be 92.3%. Even such a low percentage of remaining fabric pieces can pose a risk to the subsequent carding process if the pieces of fabric in the staple-fiber spinning process cannot be opened or removed before the actual carding process (between cylinder and flats).

Determination of Fiber Quality

Bale 100%

Fabric pieces with knitted structure in the bale (7.65%) in enlargement

Fig. 2: The degree of fabric opening is decisive for an optimal processing in staple-fiber spinning.

Source: TIS 28967/Technology & Process Analytics

3.2. Efficiency of Fiber Opening from the Tearing Process

In addition to the criterion concerning the number of fabric pieces remaining after the fiber preparation process, the quantity of fibers that are opened after the tearing process is a further important criterion. In this case, fiber fragments that do not benefit the staple-fiber spinning process, or that will definitely be removed during the staple-fiber spinning process, are also taken into account.

To this effect, the fibers that have already been opened successfully are defined in relation to the fibers that are still to be opened and the fiber fragments, as follows.

To calculate the key figure, a test method has been determined that selects the fibers that have not been opened or damaged. The data calculated using the test method must be as close as possible to manual selection. The proportions are then determined using gravimetric analysis. After comparing the various measuring methods on the market, the Shirley test device proved ideal for the selection process.

$$\textit{Efficency of fiber opening EFO [\%]} = \frac{\textit{raw material} - \textit{non-opened fibers} - \textit{fiber fragments}}{\textit{raw material}} \times 100$$

Evaluation of Efficiency of Fiber Opening with Shirley

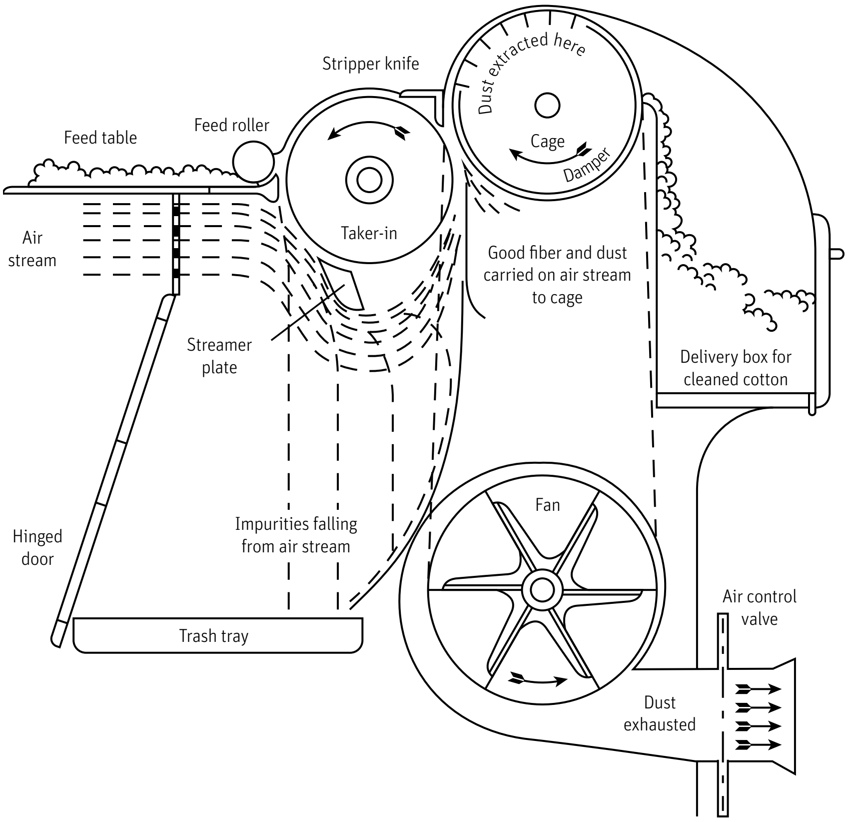


Fig. 3: The Shirley test device ideally measures the efficiency of fiber opening of the tearing process.

Source: TIS 28967/Technology & Process Analytics

The determination quality of the Shirley device was confirmed by selection results that closely approximated those of manual selection.

Efficiency of Fiber Opening Evaluation by Shirley

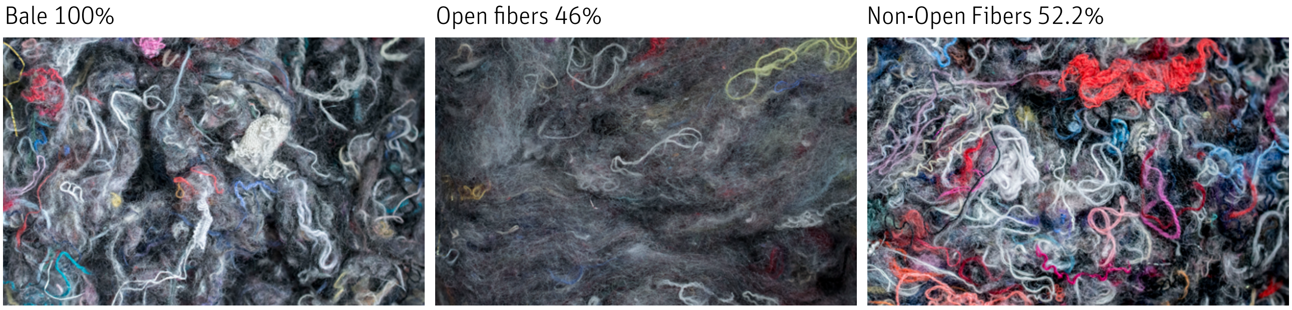

Bale 100%
Open fibers 46%
Non-Open Fibers 52.2%

Fig. 4: The fiber opening done by Shirley

Source: TIS 28967/Technology & Process Analytics

Efficiency of Fiber Opening Evaluation by Hand

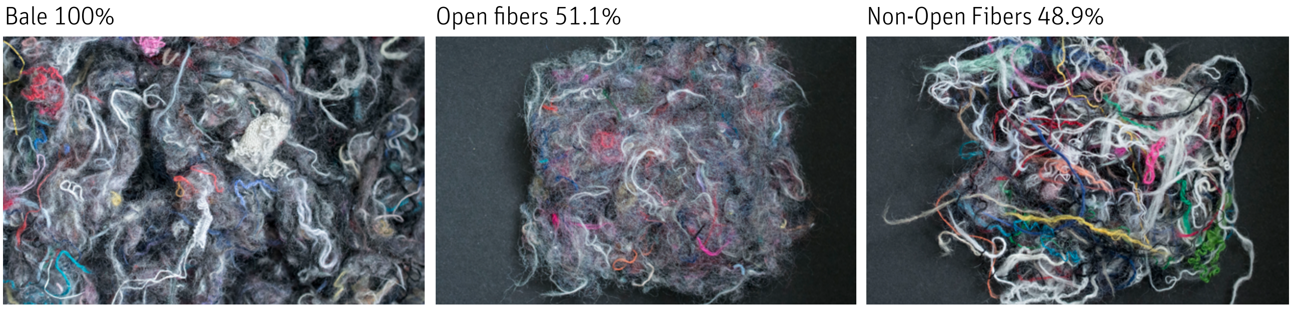

Bale 100%
Open fibers 51.1%
Non-Open Fibers 48.9%

Fig. 5: The fiber opening done by hand

Source: TIS 28967/Technology & Process Analytics

Therefore using the Shirley test device for the selection process results in an efficiency of fiber opening (EFO) of 46%. This must then be increased significantly, either during fiber opening within the tearing processes, or in the downstream staple-fiber spinning process. As with cotton cleaning, it is recommended that recycled fibers should ideally be opened at the start of the process chain.

With regard to fiber opening, the following specific values can currently be summarized and estimated for the future processing of post-consumer raw materials.

	Rieter Trial [%]	Requirements for the Future [%]
Degree of Fabric Opening	92.3	98
Efficiency of Fiber Opening	46	70

3.3. Fiber Length Characteristics

The fiber lengths are important key figures after the tearing process and are used to determine the downstream spinning process to be used (ring or rotor), the quality (evenness), and the maximum spinning count (yarn counts).

Studies conducted in recent years have shown that three fiber length characteristics are of great importance for the classification of quality:

- Short-fiber content [%]
- Mean fiber length [mm]
- 5% fiber length [mm]

These fiber length characteristics depend on whether the material is more difficult to open (usually referred to as “post-consumer”) or easy to open (usually referred to as “pre-consumer”). Another criterion is whether the fabric within the post-consumer raw material is knitted or woven, i.e. the fabric construction.

In recent years, the most important fiber characteristic values have been recorded for the different raw material categories.

Short-Fiber Content at All Positions

Different recycling fibers

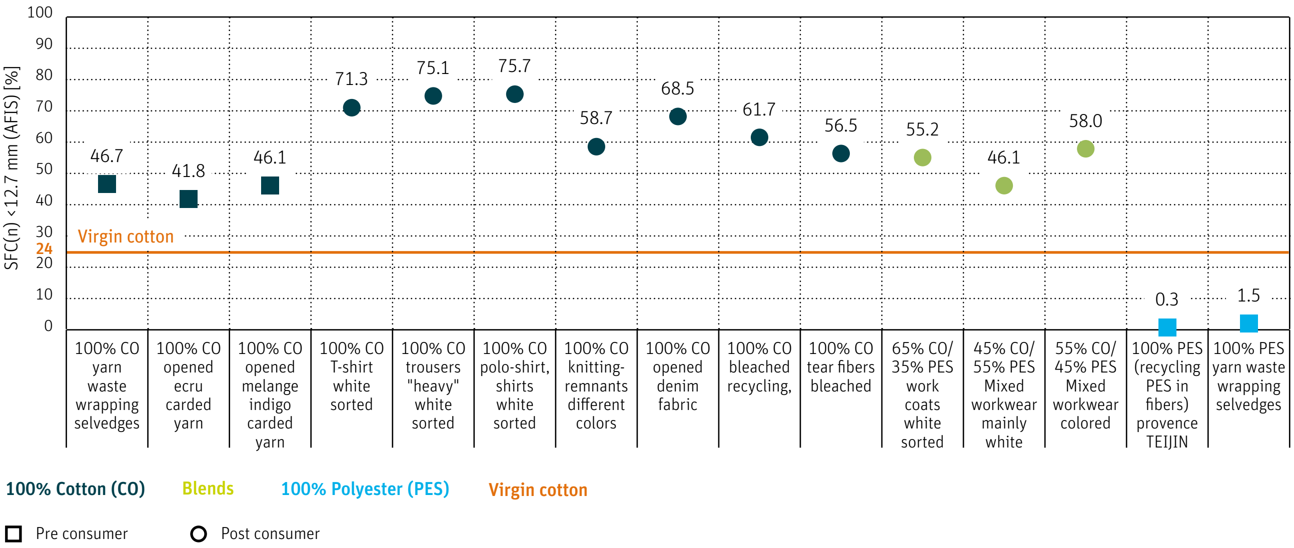
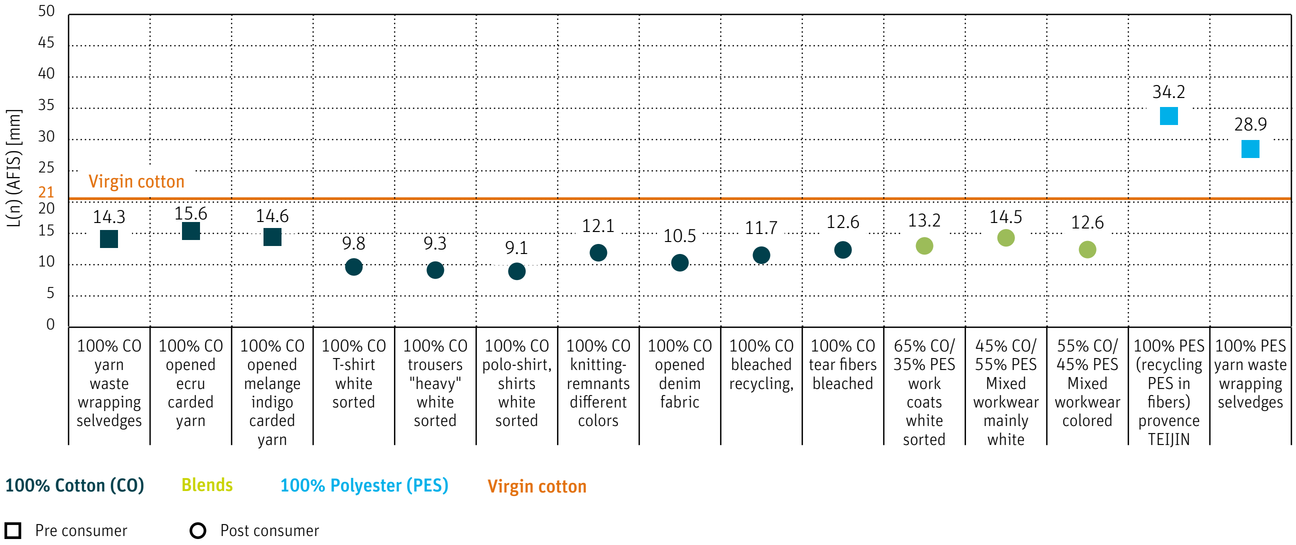


Fig. 6: The short-fiber content of post-consumer material is higher because it is more difficult to open.

Source: TIS 28487, 28178, 28572, 28669, 29074 / Technology & Process Analytics

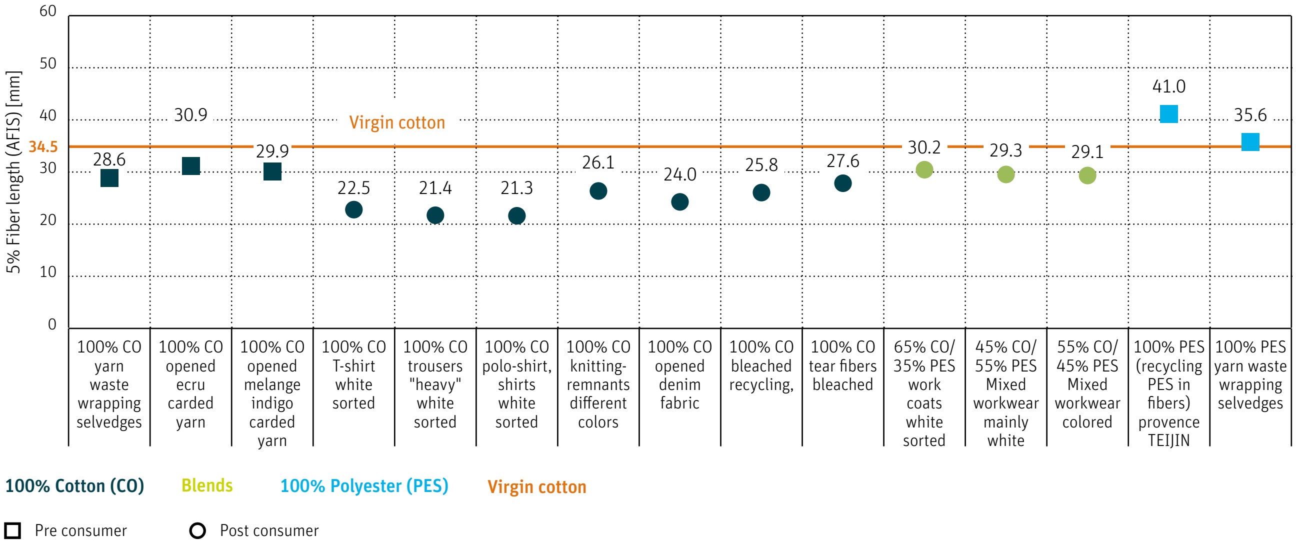


Mean Fiber Length at All Positions

Different recycling fibers

Fig. 7: Post-consumer material shows a shorter mean fiber length.

Source: TIS 28487, 28178, 28572, 28669, 29074 / Technology & Process Analytics



Long Fiber Content at All Positions

Different recycling fibers

Fig. 8: Also long fiber content is less with post-consumer material.

Source: TIS 28487, 28178, 28572, 28669, 29074 / Technology & Process Analytics

Using this information, the following classification has been determined. The classes have so far allowed for very good estimates in terms of processability and yarn quality.
Up to recycling class "medium", fibers with a blend containing a maximum of 75% recycled fibers can be processed using ring spinning technology. For better recycling classes and materials that use man-made fibers as a virgin component, a blend containing up to a maximum of 87.5% recycled fibers can be achieved. The maximum recycled fiber percentage that will stabilize in the market depends on how the requirements for quality, productivity, and efficiency are met. Today, the target for admixing recycled fibers is between 25% and a maximum of 50%, and this is often achieved. This percentage will increase on the market if the coordination of technical resources and coordination between the industrial sectors involved improves.

Due to the fiber damage and/or fiber shortening resulting from the unavoidable fiber stress during the mechanical opening of the fibers, the downstream staple-fiber spinning process must never cause any further stress or shortening.

Rieter Recycling Classification

Fiber key parameters for recycling, developed from AFIS System

Classification	Short-Fiber Content	Mean Fiber Length	5% Fiber Length
Very good	45%	17 mm	31 mm
Good	55%	14 mm	29 mm
Medium	60%	13 mm	28 mm
Poor	78%	10 mm	22 mm
Cotton as a reference	24%	21 mm	34 mm

Fiber stress/length and fiber neps can influence each other.

The nep content should not exceed 400 – 600 neps per gram raw fiber material

Fig. 9: The Rieter Recycling Classification allows a very good estimation of processability and yarn quality of the used material.

3.4. Requirements for Raw-Material Selection and Fiber Opening

New and more stringent requirements for selecting raw materials and the fiber opening process will be introduced in the future to ensure the staple-fiber spinning process is efficient and produces high-quality products when using recycled fibers. This will also help ensure wider use of recycled raw materials.

Automated sorting by the most important technological criteria, such as raw material, fabric construction, and color will inevitably be used. It will take a long-term, cross-border approach to identify technologies for this purpose that already exist or can be developed in the future.

From the technological process analyses that have been conducted to date, a number of key areas for optimization and priorities for raw-material extraction have been identified in relation to fiber opening:

Sorting by

- Type of raw material
- Type of fabric construction (woven/knitting)
- Fabric color

Opening Machinery Design and Setting

- Wires or pins of opening points
- Number of opening points
- Specific settings depending on fabric construction

Opening Equipment

- Reduction of “fiber metal stress” by using auxiliary materials such as liquids

The requirement for increased use of recycled raw materials in the textile sector will continue to increase in the future. Reasons include limited raw material resources (particularly cotton), increasing consumer awareness in terms of the environment, and existing legal recycling requirements in specific countries.

The further expansion of the existing recycling industry will, however, require adaptation and optimizations throughout the entire textile recycling value chain.

The recycling market will continue to grow intensively, and the faster the individual industrial sectors become more coordinated, the better. These include:

- Raw-material procurement/sorting
- Fiber opening
- Staple-fiber spinning process
- Further processing of the yarn
- Equipment
- Retailers

This will help to drive system development for the preparation and processing of recycled fibers.

Closing the Loop in the Textile Industry

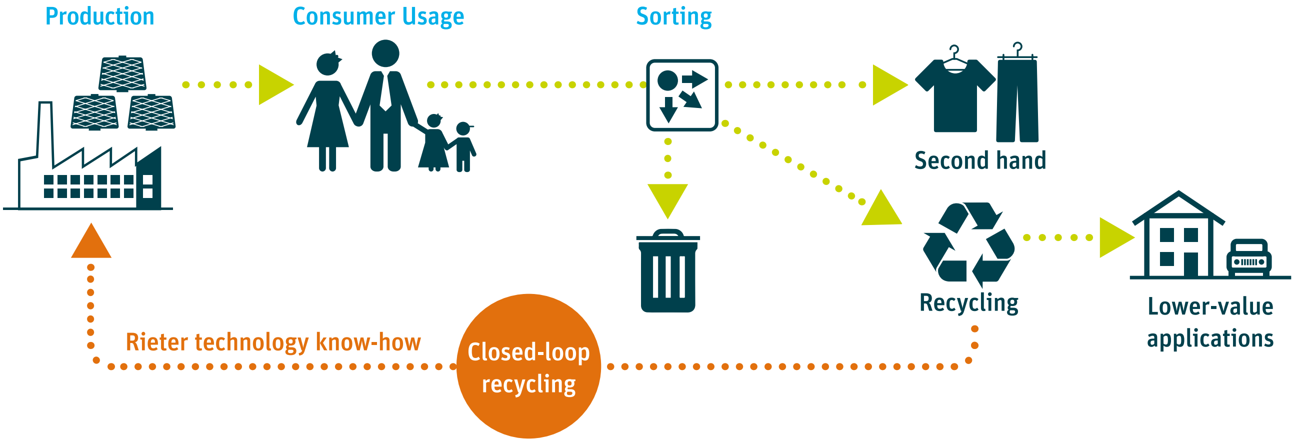


Fig. 10: One of the goals within the textile industry is to “close the loop,” which refers to the process of recycling and reusing products without material loss.

Source: TIS 28572 / Technology & Process Analytics

4. Market Potential

Currently, the global market potential for further processing raw materials for mechanical and chemical recycling can only be estimated up to 2030 on the basis of fiber production and technical and logistical factors.

In 2019, the estimate of collected textile waste in Europe is 2.8 million tons per year (Source: Euratex). The estimation for Germany are 1.3 million tons of raw material currently reclaimed from textiles every year. In Switzerland, the figure quoted by Texaid is 86 000 tons per year. Of course, only a small portion of the collected raw materials is returned to the recycling process today. The consideration should only show which raw material potential is available in Europe alone. Therefore it is obvious to do more research and development to recycle the large amount of raw material resources of the textile value chain.

Related to the cotton raw material, a recycling percentage of around 25% can be assumed by 2030 on the basis of growing demand, legislative changes for better use of raw materials and the technical possibilities. However, this is only an estimate. Estimates from countries such as Finland and Sweden, which are very active in the field of raw-material recovery, are much higher, at up to 35%.

For cellulose-based man-made fibers, such as viscose, modal, and lyocell, the percentage is approximately 10%, since the input fibers are also often used for hygiene products and are therefore not recyclable. For other man-made fibers, the figure is also around 10%, as the recyclable raw material is already used primarily for PET bottles. These figures mean that for the staple fiber industry, the realistic market potential for recycled raw materials amounts to around 7.6 million tons annually.

Market Potential for Recycled Materials

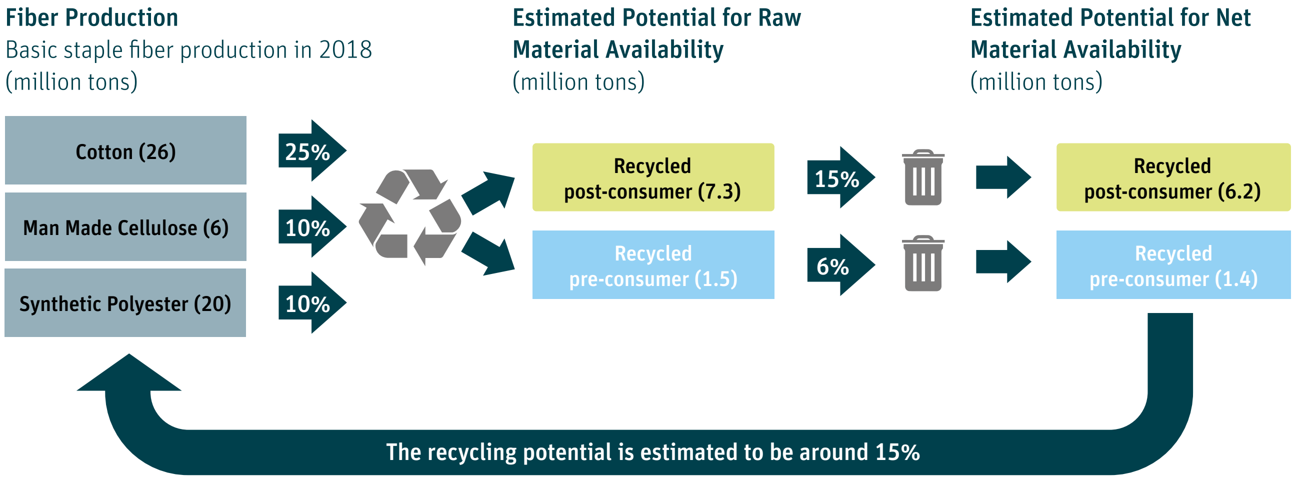


Fig. 11: The realistic market potential for recycled raw materials amounts to around 7.6 million tons annually

Source: TIS 28572 / Technology & Process Analytics

5. Staple Fiber Spinning Process

The application with the highest demand for recycled materials is blending recycled cotton with virgin cotton. This application was used to determine the optimal spinning process by calculating both the requirements for raw-material preparation and the optimal machine configuration for spinning staple fibers.

The first stage of this study focused on recycled post-consumer fibers opened mechanically (tear fibers), and its blends with virgin cotton. The possibility of expanding the recycling market and the possible applications for both rotor yarn and primarily ring yarn was also evaluated.

To evaluate the quality, performance, and optimum process sequence, a bleached “post-consumer raw material” categorized as “good” was selected according to the previously defined fiber length characteristics. This raw material was then blended with a virgin cotton of 1 1/8 inch commercial staple. A tuft blending process was used, as blending carrier fibers at the beginning of the staple-fiber spinning process results in higher operational reliability and quality during each process step.

Characteristics of the used raw materials	**Measuring device**	**Tear fibers**	**Virgin cotton**	
Raw material		Cotton bleached	Virgin cotton	
Provenience		Tear fibers from knitted fabrics	Chad	
Commercial staple UQL (w) [mm]	AFIS	23.4	30.0	Fiber length
Short-fiber content < 12.7 mm (n) [%]	AFIS	56.5	22.4	
Mean fiber length L (n) [mm]	AFIS	12.6	20.2	
Mean fiber length CV% L(n) [%]	AFIS	63.8	47.0	
5% fiber length (n) [mm]	AFIS	27.6	33.9	
Fiber fineness [dtex] **Fiber fineness** [Mic]	Vibrojet HVI	2.31 [dtex]	4.14 [Mic] (1.63 dtex calculated)	Fineness
Tenacity [cN/tex]	Vibrojet	22.4	20.9	Tenacity/ Elongation
Elongation [%]	Vibrojet	6.7	8.9	

Source: TIS 28572 / Technology & Process Analytics

100% CO, Tear fibers, bleached

Raw material

Non-opened fibers

Quality check of tear fiber length

Fig. 12: Raw material

Source: TIS 28178 / Technology & Process Analytics

The study showed that the maximum blend percentage of recycled fibers in the respective raw-material composition is 75%, as this ensures that the end fiber construction can be processed using a spinning process.

The spinning plan covers admixing recycled fibers up to the respective maximum of 75% with 25% virgin cotton. For comparability and to determine the optimal process sequence for the various raw-material blends, the production outputs were kept constant and based on the highest achievable recycled blend ratio. This allowed the optimal process sequence within the spinning process to be determined depending on the blend ratio.

Different Spinning Processes

To determine the optimal process sequence, the following spinning processes for ring and rotor were used for the various raw-material blends.

Direct Process Rotor Spinning

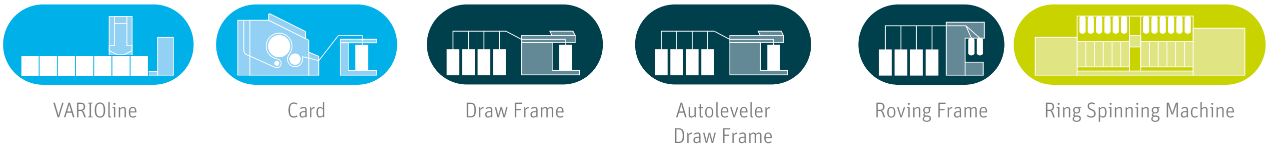
Direct Process Ring Spinning

Shortened Process Rotor Spinning

Shortened Process Ring Spinning

Twin Yarn Process Compact Spinning

Classical Process Ring Spinning



Source: Technology & Process Analytics

Spinning Plan for Processing a Blend of 75% Tear Fibers and 25% Virgin Cotton

	Machine	Feed [tex]	Doubling [fold]	Draft [fold]	Output [tex]	Twist [ae]/[T/m]	Delivery	
	Blowroom	Virgin Cotton: A 12 – B 12 – B 34 – A 81 – A 79 Tear Fibers: ----------------- B 34 – A 81 – A 79						
Direct process	Card (with 32 flats in operation)				16 000		80 kg/h	
	with Module	16 000	1	2.3	7 000			
	Rotor Spinning Machine	7 000	1	237	30	4.7/828	130 000 rpm	Rotor 33-XT-BD
	Roving Frame	7 000	1	9.3	738	2.27/80	1 000 rpm	
	Ring Spinning Machine	738	1	15 20 25	49 37 30	4.7/641 4.7/740 4.7/828	14 000 rpm 15 000 rpm 16 000 rpm	Ring ∅ 42 mm
Shortened process	Card (with 32 flats in operation)				7 000		80 kg/h	
	Draw Frame	7 000	6	6	7 000		500 m/min	
	Rotor Spinning Machine	7 000	1	237	30	4.7/828	130 000 rpm	Rotor 33-XT-BD
	Roving Frame	7 000	1	9.3	738	2.27/80	1 000 rpm	
	Ring Spinning Machine	738	1	15 20 25	49 37 30	4.7/641 4.7/740 4.7/828	14 000 rpm 15 000 rpm 16 000 rpm	Ring ∅ 42 mm
Twin yarn process	Card (with 32 flats in operation)				7 000		80 kg/h	
	Draw Frame	7 000	6	8	5 250		500 m/min	
	Roving Frame	5 250	1	14.2	369		1 000 rpm	
	Compact Spinning Machine	2 x 369	2	25	30	4.7 / 828	16 000 rpm	Ring ∅ 42 mm

Source: TIS 28178 / Technology & Process Analytics

Spinning Plan for Processing a Blend of 50% Tear Fibers and 50% Virgin Cotton

	Machine	Feed [tex]	Doubling [fold]	Draft [fold]	Output [tex]	Twist [ae]/[T/m]	Delivery	
	Blowroom	Virgin Cotton: A 12 – B 12 – B 34 – A 81 – A 79 Tear Fibers: ----------------- B 34 – A 81 – A 79						
Direct process	Card (with 32 flats in operation)				16 000		80 kg/h	
	with Module	16 000	1	2.3	7 000			
	Rotor Spinning Machine	7 000	1	237	30	4.7/828	130 000 rpm	Rotor 33-XT-BD
	Roving Frame	7 000	1	9.3	738	1.99/70	1 000 rpm	
	Ring Spinning Machine	738	1	15 20 25	49 37 30	4.7/641 4.7/740 4.7/828	14 000 rpm 15 000 rpm 16 000 rpm	Ring ∅ 42 mm
Shortened process	Card (with 32 flats in operation)				7 000		80 kg/h	
	Draw Frame	7 000	6	6	7 000		500 m/min	
	Rotor Spinning Machine	7 000	1	237	30	4.7/828	130 000 rpm	Rotor 33-XT-BD
	Roving Frame	7 000	1	9.3	738	1.99/70	1 000 rpm	
	Ring Spinning Machine	738	1	15 20 25	49 37 30	4.7/641 4.7/740 4.7/828	14 000 rpm 15 000 rpm 16 000 rpm	Ring ∅ 42 mm
Twin yarn process	Card (with 32 flats in operation)				7 000		80 kg/h	
	Draw Frame	7 000	6	8	5 250		500 m/min	
	Roving Frame	5 250	1	14.2	369		1 000 rpm	
	Compact Spinning Machine	2 x 369	2	25	30	4.7 / 828	16 000 rpm	Ring ∅ 42 mm

Source: TIS 28178/Technology & Process Analytics

Spinning Plan for Processing a Blend of 25% Tear Fibers and 75% Virgin Cotton

	Machine	Feed [tex]	Doubling [fold]	Draft [fold]	Output [tex]	Twist [ae]/[T/m]	Delivery	
	Blowroom	Virgin Cotton: A 12 – B 12 – B 34 – A 81 – A 79 Tear Fibers: ----------------- B 34 – A 81 – A 79						
Direct process	Card (with 32 flats in operation)				16 000		80 kg/h	
	with Module	16 000	1	2.3	7 000			
	Rotor Spinning Machine	7 000	1	237	30	4.7/828	130 000 rpm	Rotor 33-XT-BD
	Roving Frame	7 000	1	9.3	738	1.71/60	1 000 rpm	
	Ring Spinning Machine	738	1	15 20 25	49 37 30	4.7/641 4.7/740 4.7/828	14 000 rpm 15 000 rpm 16 000 rpm	Ring ∅ 42 mm
Shortened process	Card (with 32 flats in operation)				7 000		80 kg/h	
	Draw Frame	7 000	6	6	7 000		500 m/min	
	Rotor Spinning Machine	7 000	1	237	30	4.7/828	130 000 rpm	Rotor 33-XT-BD
	Roving Frame	7 000	1	9.3	738	1.71/60	1 000 rpm	
	Ring Spinning Machine	738	1	15 20 25	49 37 30	4.7/641 4.7/740 4.7/828	14 000 rpm 15 000 rpm 16 000 rpm	Ring ∅ 42 mm
Twin yarn process	Card (with 32 flats in operation)				7 000		80 kg/h	
	Draw Frame	7 000	6	8	5 250		500 m/min	
	Roving Frame	5 250	1	14.2	369	1.19 / 59	1 000 rpm	
	Compact Spinning Machine	2 x 369	2	25	30	4.7 / 828	16 000 rpm	Ring ∅ 42 mm
Classical process	Card (with 32 flats in operation)				7 000		80 kg/h	
	Draw Frame first passage	7 000	6	6	7 000		500 m/min	
	Draw Frame second passage	7 000	6	6	7 000		500 m/min	
	Roving Frame	7 000	1	9.3	738	1.71/60	1 000 rpm	
	Ring Spinning Machine	738	1	15 20 25	49 37 30	4.7/641 4.7/740 4.7/828	14 000 rpm 15 000 rpm 16 000 rpm	Ring ∅ 42 mm

Source: TIS 28178/Technology & Process Analytics

6. Fiber Preparation

Fiber preparation before the card must be configured differently when preparing recycled fibers in comparison to a cotton line. Blending with cotton virgin fibers must also ensure the appropriate dosing of the individual components and the long-term homogeneity of the recycled fibers. There are various options that can be used in the process sequence, depending on quality requirements. This study focused on dosing two raw-material components, and not on the long-term homogeneity of the recycled components. This is due to the fact that the recycled raw material came from the same production batch and only a small, but constant, feed lot. Depending on the homogeneity requirements, a mixing chamber can therefore be used at the start of the process for the recycled raw material, or after the dosing unit for the two raw material components for long-term homogeneity.

The fiber length characteristic values are an essential criterion so that there can be no further fiber damage in the staple-fiber spinning process. There must be no increase in short fibers and no decrease in medium and long fibers (5% fiber length). This is achieved by using the correct process setup, settings, and technology components.

Short-Fiber Content during Process Stages

Virgin CO 29.7mm, 4.1 Mic./Tear fibers CO

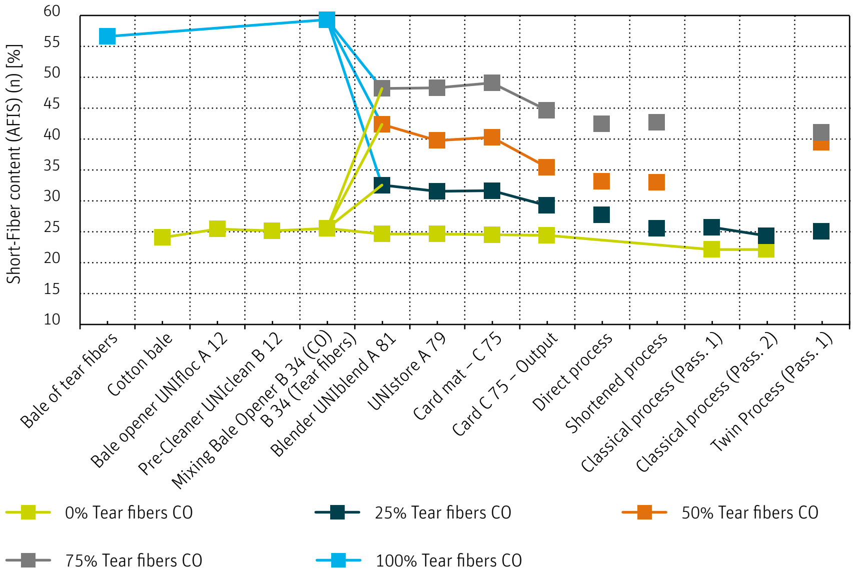


Fig. 13: The short-fiber content from bale to draw frame sliver

Source: TIS 28178 / Technology & Process Analytics

Mean Fiber Length during Process Stages

Virgin CO 29.7mm, 4.1 Mic./Tear fibers CO

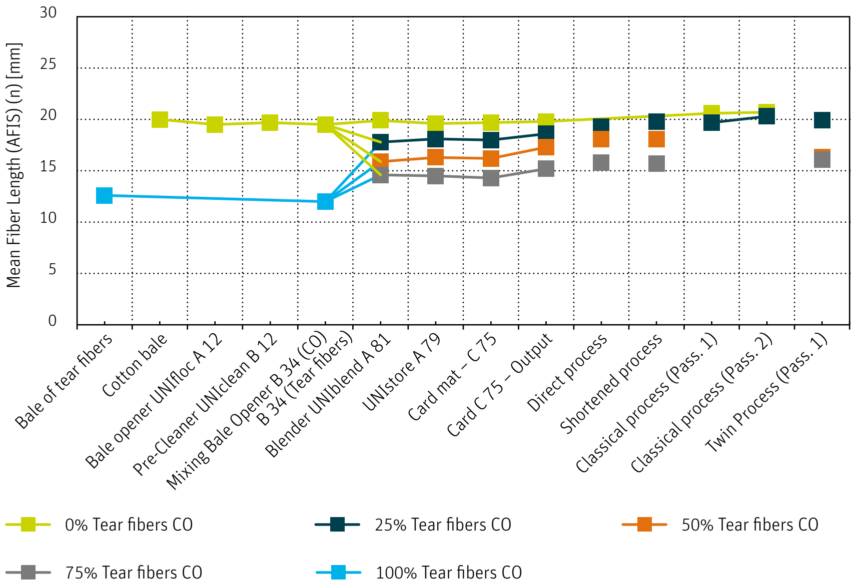


Fig. 14: The mean fiber length from bale to draw frame sliver

Source: TIS 28178 / Technology & Process Analytics

In terms of the card, using the optimal card type (for example the C 75), correct card clothing, and settings are crucial factors. The card type here represents the correct carding length between the cylinder and the card flat rods. The correct card clothing and settings enables the best-possible fiber transfer from the cylinder to the doffer and from the doffer to the concentration of web. This achieves a card production rate of 80 kg/h and reduces the number of neps, which is also the case for virgin cotton.

5% Fiber Length during Process Stages

Virgin CO 29.7mm, 4.1 Mic./Tear fibers CO

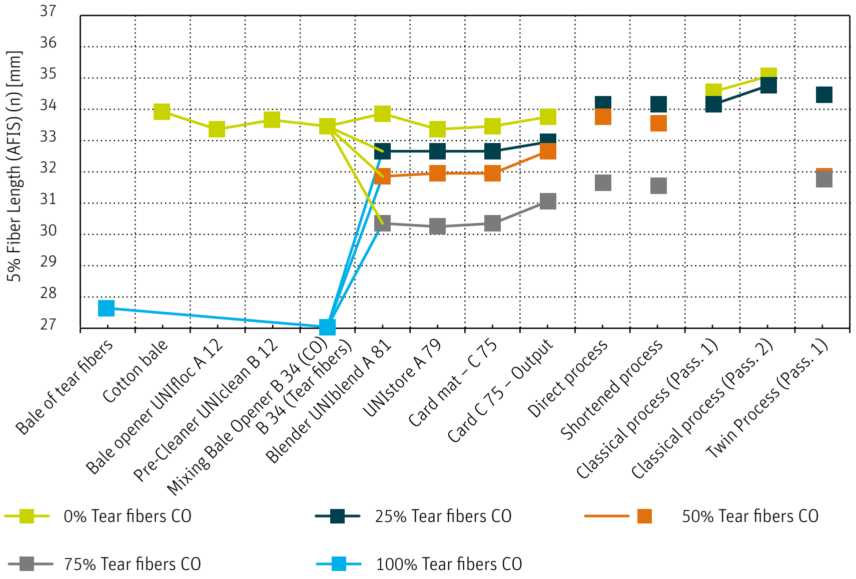


Fig. 15: The long fibers from bale to draw frame sliver

Source: TIS 28178 / Technology & Process Analytics

Neps during Process Stages

Virgin CO 29.7mm, 4.1 Mic./Tear fibers CO

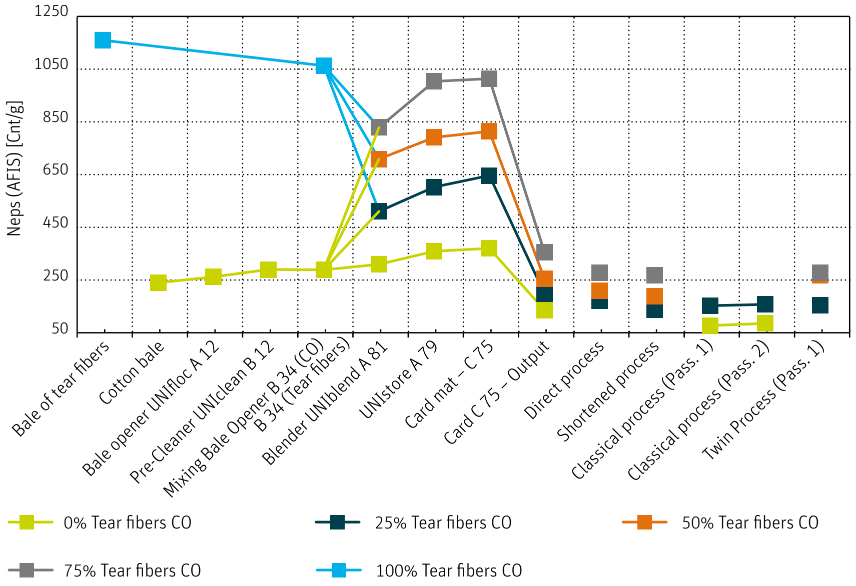


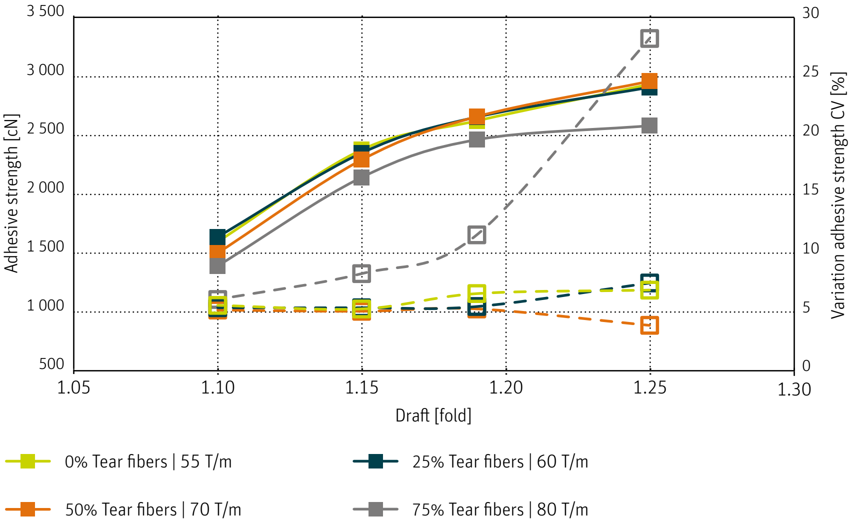
Fig. 16: The neps from bale to draw frame sliver

Source: TIS 28178 / Technology & Process Analytics

The effective clamping line distances in the main field are crucial settings for the downstream draw frame passage. In some cases, insufficient clamping line distances can be optimized slightly thanks to the draft division between the break draft and the main draft. This is achieved by increasing the break draft height and lowering the main draft height. Optimal distances adapted to the fiber length are preferred.

Due to the shorter fiber length in comparison to virgin cotton, at the roving frame it is important to approach the limits of the maximum roving adhesive strength of 2900 cN, if possible. Otherwise, it is not possible to achieve even drafting at the ring spinning machine due to the fiber mass distribution in the roving. The “roving adhesive strength variation” measured at the different drafts on the Rothschild meter indicates that the break draft height on the ring spinning machine should never be set to higher than 1.25 fold. Otherwise, the break draft on the ring spinning machine has a negative influence on drafting and therefore on yarn evenness, depending on the tear-fiber content in the blend.

The higher the tear-fiber content, the greater the twist coefficient or number of twists on the roving.

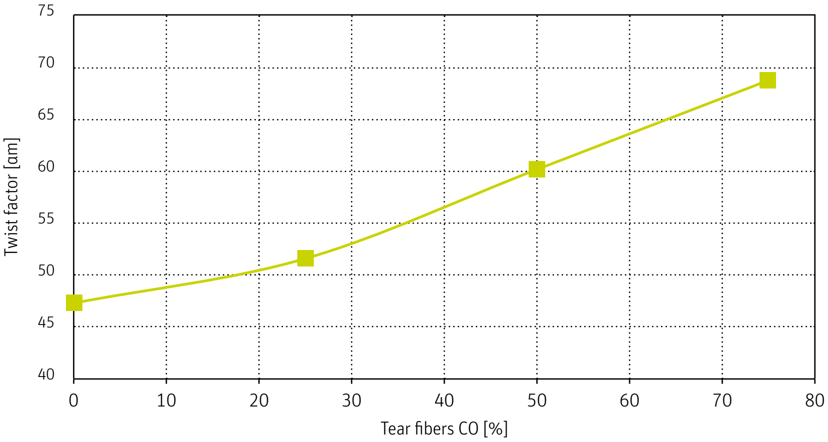


Roving Adhesive Strength and Variation

Virgin CO 29.7mm, 4.1 Mic./Tear fibers CO, Ne 0.8

Fig. 17: The adhesive strength indicates the break draft height on the ring spinning machine.

Source: TIS 28178 / Technology & Process Analytics



Twist Factor with Increasing Share of Tear Fibers

Virgin CO 29.7mm, 4.1 Mic./Tear fibers CO, Ne 0.8

Fig. 18: The higher the proportion of recycled material, the higher the torsion and the lower the productivity at the roving frame.

Source: TIS 28178 / Technology & Process Analytics

7. Yarn Quality for Ring Yarn

7.1. Unevenness

Unevenness increases as the content of tear fibers increases. Up to a tear fiber share of 50%, unevenness is 4% higher in absolute terms in comparison to a virgin raw material. It is only at a recycled content of 75% that unevenness values greatly exceed those achieved using a virgin raw material. In practice, comparing the quality to a virgin raw material is less relevant than considering for which product a yarn with greater unevenness can be used. In terms of processability and quality, however, 75% was established as the limit for the recycled fiber content.

The greater the tear-fiber content, the smaller the difference between yarn counts. One important finding is that use of one draw frame passage is the optimal choice for processing recycled fibers in blends. Neither the direct process using an RSB-Module nor the classic process using two draw frame passages are suitable for this process. One argument against the direct process is that, in addition to short fibers, both the recycled fibers and those admixed with virgin cotton have sufficient carrier fibers for an optimal draft process. Even at a tear-fiber content of 75%, the short-fiber content is only approximately 42% and therefore not yet within the range where a direct process is recommended.

Unevenness at Different Draw Frame Passages

Virgin CO 29.7mm, 4.1 Mic./Tear fibers CO, Ring yarn, αe 4.7

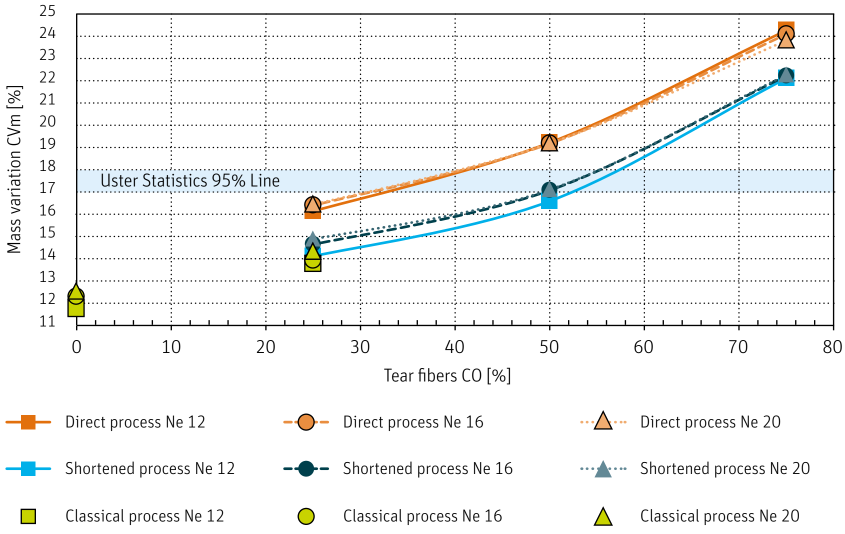


Fig. 19: Up to a tear fiber count of 50%, unevenness is 4% higher in absolute terms in comparison to a virgin raw material.

Source: TIS 28178 / Technology & Process Analytics

Nevertheless, due to the smaller total draft, the direct process results in a larger sliver adhesion length overall, which usually involves fewer drafting errors, thus resulting in slightly better unevenness in the long-wave cutting length range. For this reason, the draft at the draw frame passage and the doubling must never be set to more than 6 fold. If finer slivers are to be produced as a result of fine roving, doubling should be reduced to 4 fold. In the classic process, the total drafts would therefore already be too high to achieve an even draft on the sliver.

7.2. Neps

Fiber nep formation is influenced far more by the fiber tearing process than by fiber preparation as part of the staple-fiber spinning process. This is why the number of neps in the yarn is already much higher in a blend containing a recycled fiber content of 50% in comparison to 100% virgin raw material. Both the unevenness and the neps indicate that a blend containing 50% recycled fiber already results in an unique yarn structure. The applications for further processing the yarn must therefore be selected in line with quality and design requirements.

Neps at Different Draw Frame Passages

Virgin CO 29.7mm, 4.1 Mic./Tear fibers CO, Ring yarn, αe 4.7

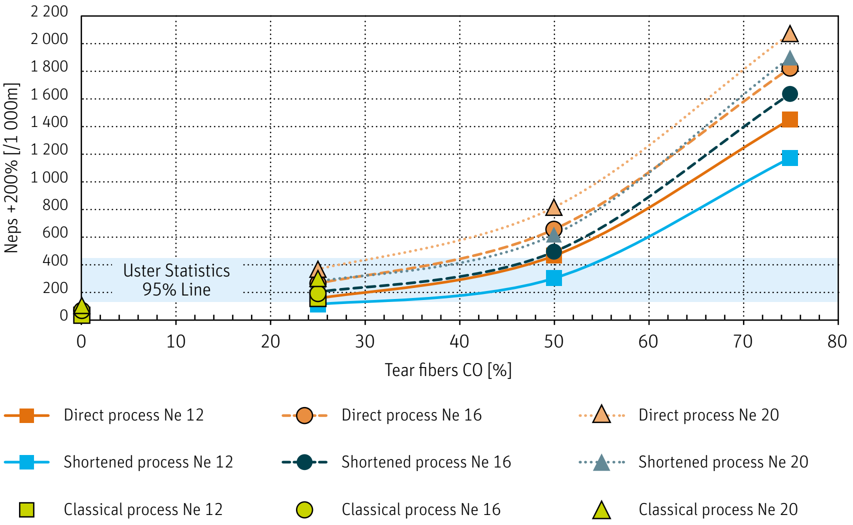


Fig. 20: A blend with 50% recycled fibers shows higher neps compared to 100% virgin cotton and result in a unique yarn structure.

Source: TIS 28178 / Technology & Process Analytics

7.3. Tenacity and Elongation

Tenacity reduces as the recycled and short-fiber content increases. The shortened drafting process produces a yarn tenacity that is, in absolute terms, 0.5 cN/tex higher than the direct process.

If an average minimum tenacity of 12 cN/tex, a yarn count range of between Ne 12 and Ne 20, a weakness of 8 cN/tex and an average elongation of 2% are assumed for air-jet weaving machines, yarns with a recycled content of 75% would still be usable for weft weaving in weaving mills.

Breaking Tenacity at Different Draw Frame Passages

Virgin CO 29.7mm, 4.1 Mic./Tear fibers CO, Ring yarn, αe 4.7

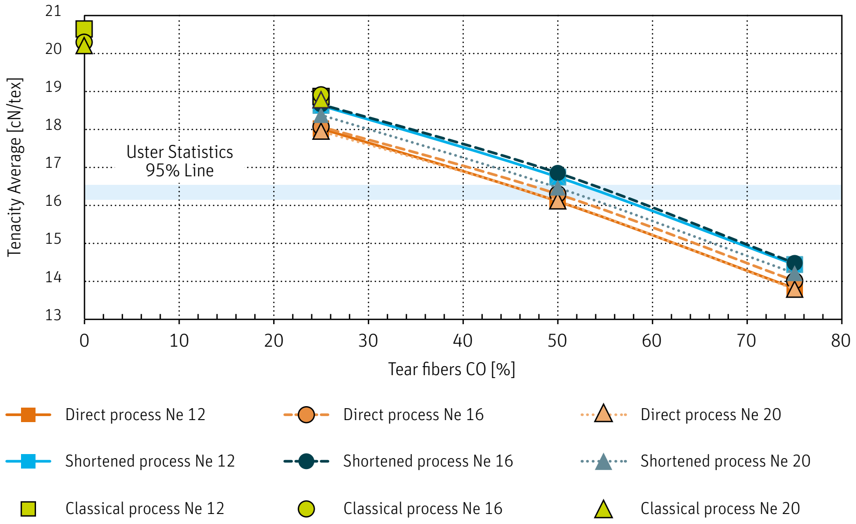


Fig. 21: With a tenacity of above 12 cN/tex all yarns in the graph can be used for weft weaving in weaving mills.

Source: TIS 28178 / Technology & Process Analytics

Breaking Tenacity at Different Draw Frame Passages

Virgin CO 29.7mm, 4.1 Mic./Tear fibers CO, Ring yarn, αe 4.7

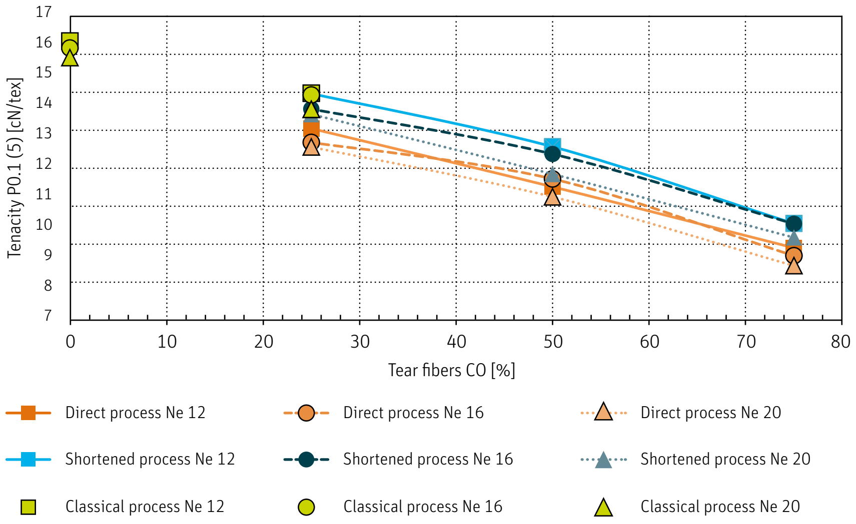


Fig. 22: The tenacity of the weak points in the yarn are around 4 cN/tex lower than the tenacity average.

Source: TIS 28178 / Technology & Process Analytics

Breaking Elongation at Different Draw Frame Passages

Virgin CO 29.7mm, 4.1 Mic./Tear fibers CO, Ring yarn, αe 4.7

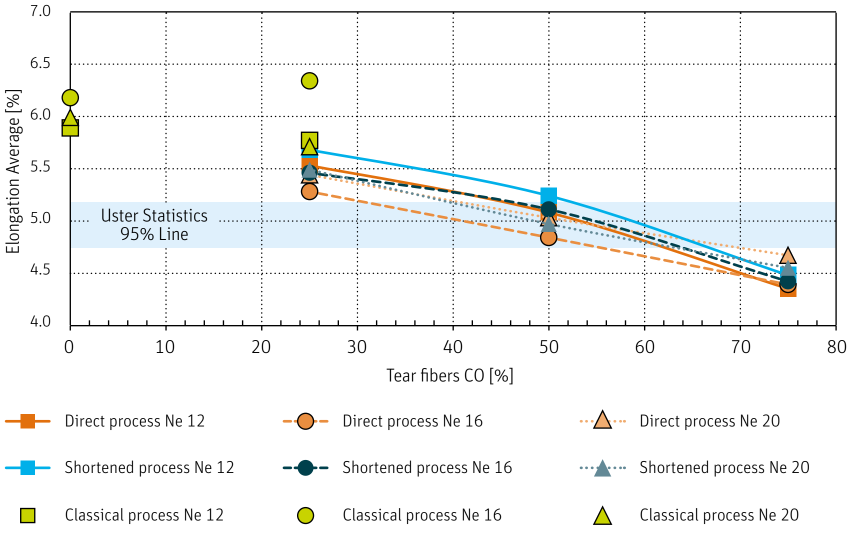


Fig. 23: With an elongation of above 2% all yarns in the graph can be used for weft weaving in weaving mills.

Source: TIS 28178 / Technology & Process Analytics

Breaking Elongation at Different Draw Frame Passages

Virgin CO 29.7mm, 4.1 Mic./Tear fibers CO, Ring yarn, αe 4.7

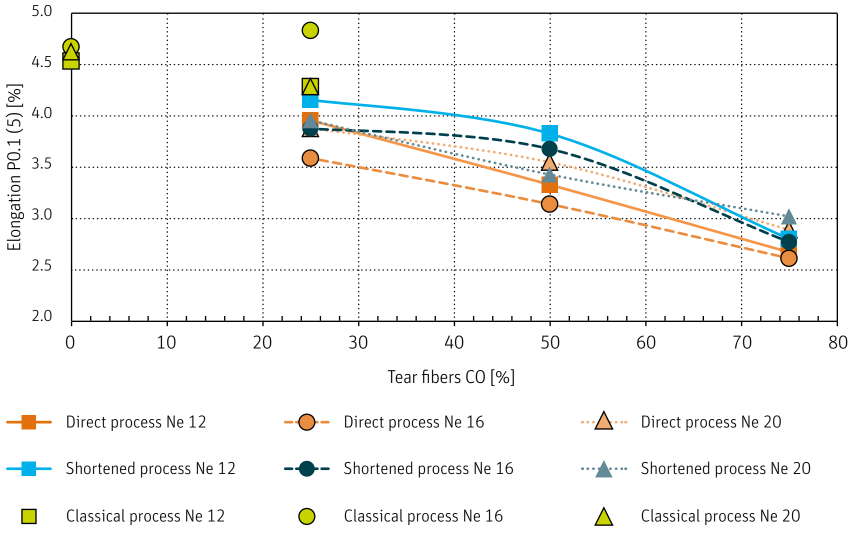


Fig. 24: The elongation of the weak points in the yarn are around 2% lower than the elongation average.

Source: TIS 28178 / Technology & Process Analytics

7.4. Hairiness/Abrasion

Hairiness is directly related to short-fiber content and therefore negatively influences abrasion. This means from a recycled content of 50%, there would be a deterioration in value-in-use characteristics such as pilling, especially in knitted fabrics. There would be less of an impact in woven fabric as a result of yarn integration. However, the finished product would still be expected to have a shorter lifespan compared to a virgin raw material. The benefit of more sustainable raw-material utilization is thus mitigated by slightly shorter lifespan for the final product. Since fashionable items often have a shorter lifespan in any case, this does not necessarily bring disadvantages for the end user.

With otherwise predominant and clear advantages for the shortened process compared to the direct process, there is slightly higher abrasion with a blend containing more than 30% recycled fibers as a result of higher fiber parallelism. From a recycled content of 50%, abrasion values from the shortened process are greater than those from the direct process. However, the advantages and disadvantages must be considered and weighted as a whole.

Hairiness at Different Draw Frame Passages

Virgin CO 29.7mm, 4.1 Mic./Tear fibers CO, Ring yarn, αe 4.7

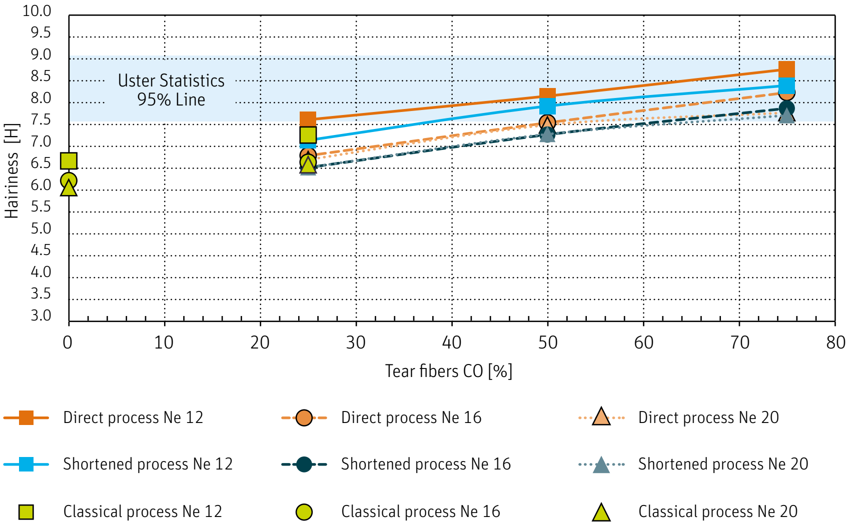


Fig. 25: Hairiness is directly related to short-fiber content and therefore negatively influences abrasion and influences the value-in-use characteristics such as pilling, especially in knitted fabrics.

Source: TIS 28178 / Technology & Process Analytics

Abrasion at Different Draw Frame Passages

Virgin CO 29.7mm, 4.1 Mic./Tear fibers CO, Ring yarn, αe 4.7

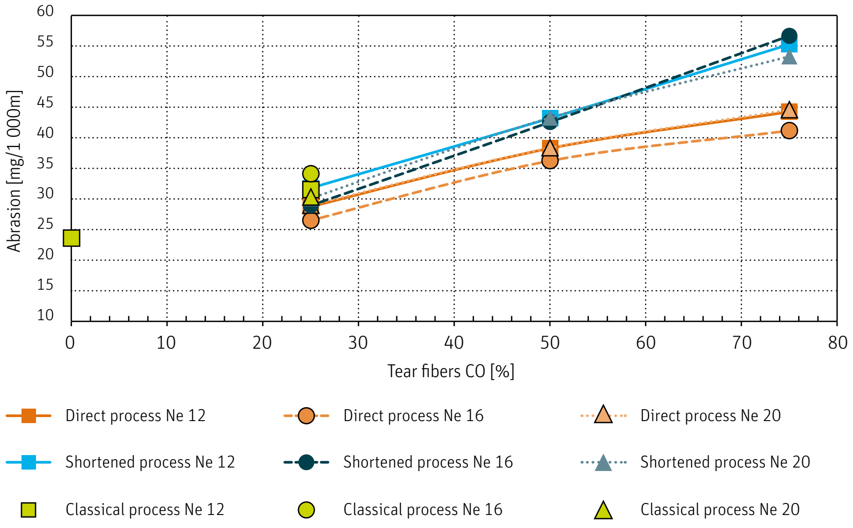


Fig. 26: From a recycled content of 50%, abrasion values from the shortened process are greater than those from the direct process.

Source: TIS 28178 / Technology & Process Analytics

7.5 Q-Package for Ring Spinning

In order to process recycled fibers on a ring spinning machine, special fiber feeding is required in drafting system. The Q-Package for use on ring and compact spinning machines for cotton has proven a reduced IPI over the entire spinning process. Without any influence on the yarn tenacity, the Q-Package reduces imperfections and Classimat faults.

Q-Package for Ring Spinning Machine

Fig. 27: Depending on fiber requirements different drafting system elements for the ring spinning machine are available.

Source: TIS 28178 / Technology & Process Analytics

8. Yarn Quality for Spin-Twist Yarn

Producing spin-twist yarns (Com4compact-twin yarn) on a compact-spinning machine can improve unevenness by a further 1% in absolute terms for a low recycled content of 25%. This equates to a relative improvement of 7%.

Producing spin-twist yarns also has a hugely positive influence on tenacity, hairiness, and abrasion. In absolute terms, the average tenacity can be increased by 2 cN/tex. Hairiness can be decreased in absolute terms by approximately one point, while abrasion is reduced by at least 50% in relative terms.

Breaking Tenacity Ring Yarn vs. Compact-Twin Yarn

Virgin CO 29.7mm, 4.1 Mic./Tear fibers CO, Shortened process, Ne 20, αe 4.7

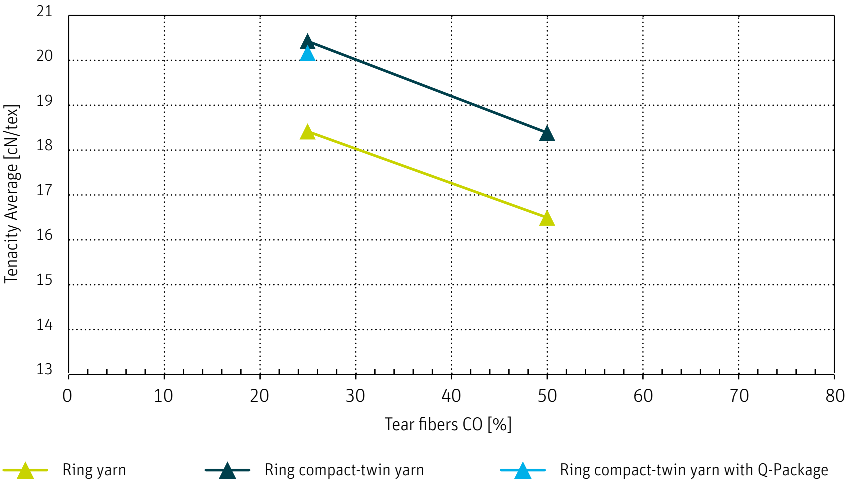


Fig. 28: With a compact-twin yarn the tenacity can be increased by 2 cN/tex compared to a single yarn.

Source: TIS 28178 / Technology & Process Analytics

Hairiness Ring Yarn vs. Compact-Twin Yarn

Virgin CO 29.7mm, 4.1 Mic./Tear fibers CO, Shortened process, Ne 20, αe 4.7

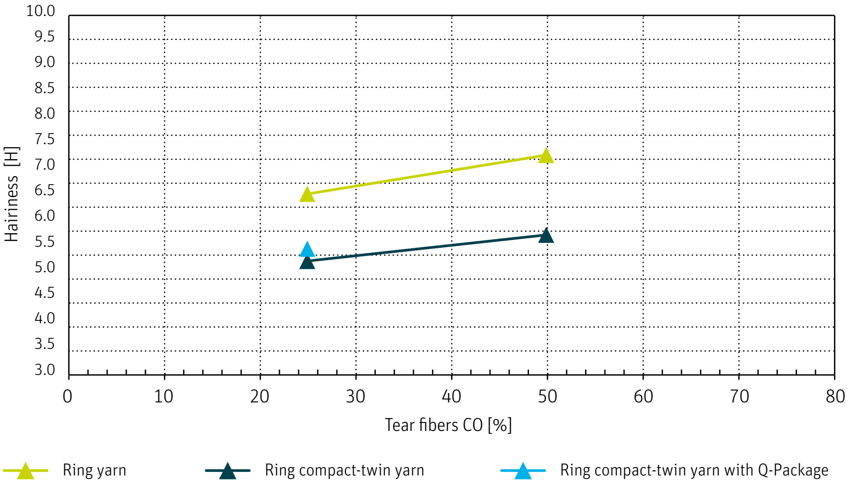


Fig. 29: With a compact-twin yarn the hairiness can be decreased by absolutely one point.

Source: TIS 28178 / Technology & Process Analytics

Abrasion Ring Yarn vs. Compact-Twin Yarn

Virgin CO 29.7mm, 4.1 Mic./Tear fibers CO, Shortened process, Ne 20, αe 4.7

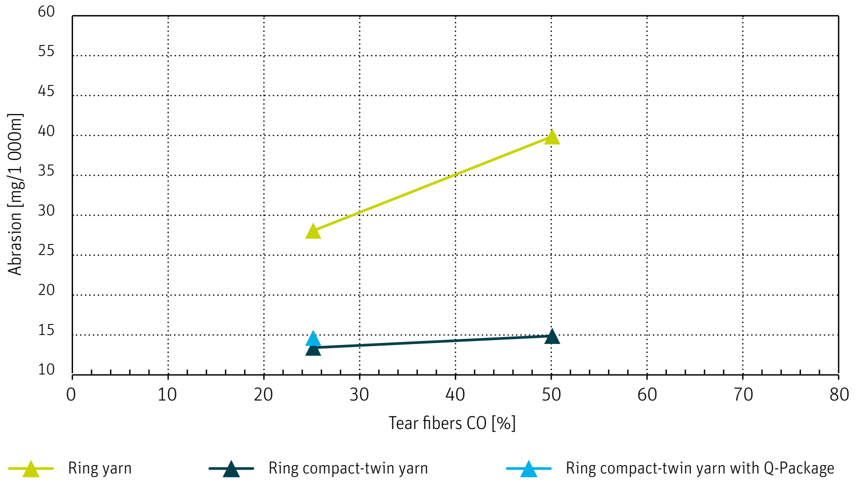


Fig. 30: With a compact-twin yarn abrasion is reduced by at least 50% in relative terms.

Source: 28178/Technology & Process Analytics

9. Yarn Quality for Rotor Yarn Compared to Ring Yarn

9.1. Unevenness

In essence, the rotor spinning machine is better suited to processing fibers with a high short-fiber content (> 30%), which is reflected in better evenness. This is due to better fiber feeding of the opened fibers in the closed fiber feed channel and the downstream doubling of the individual fibers in the rotor. The tear fibers used contained 56% short fibers and resulted in a short-fiber content of between 30% and 45%, depending on the type of blend with virgin cotton. In terms of yarn evenness, the qualitative strengths of the rotor spinning process are therefore clearly evident.

In addition, the rotor spinning process offers two options in the process sequence. The higher sliver adhesion length associated with the direct process can have a marginally beneficial impact on long-wave unevenness in a cutting length range of 1 to 3 meters. However, countering this is the lack of sliver doubling, which negatively impacts long-term homogeneity of the recycled raw material. In the rotor spinning process, two process sequences are possible: the direct process and the shortened process.

Unevenness on Ring and Rotor Yarn

Virgin CO 29.7mm, 4.1 Mic/Tear fibers CO, Ne 20, αe 4.7, Rotor 33-XT-BD

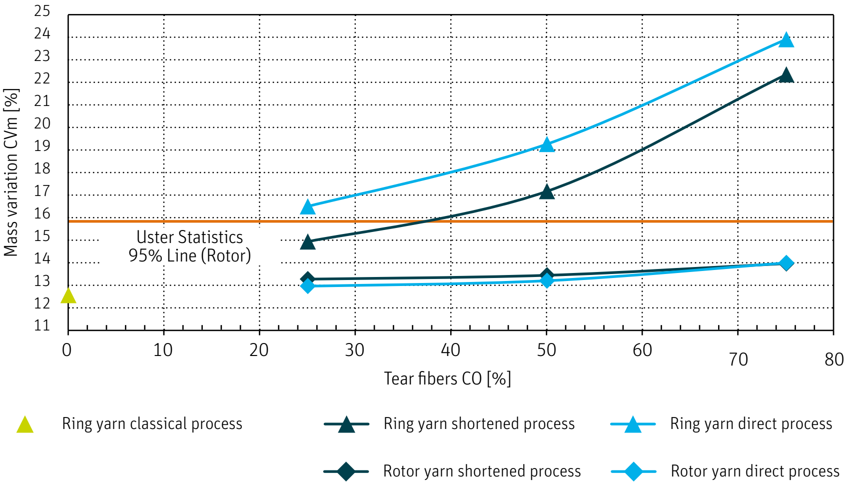


Fig. 31: The rotor spinning machine is better suited to processing fibers with a high short-fiber content which is reflected in better evenness.

Source: TIS 28178 / Technology & Process Analytics

Unevenness on Ring and Rotor Yarn

Virgin CO 29.7mm, 4.1 Mic/Tear fibers CO, Ne 20, αe 4.7, Rotor 33-XT-BD

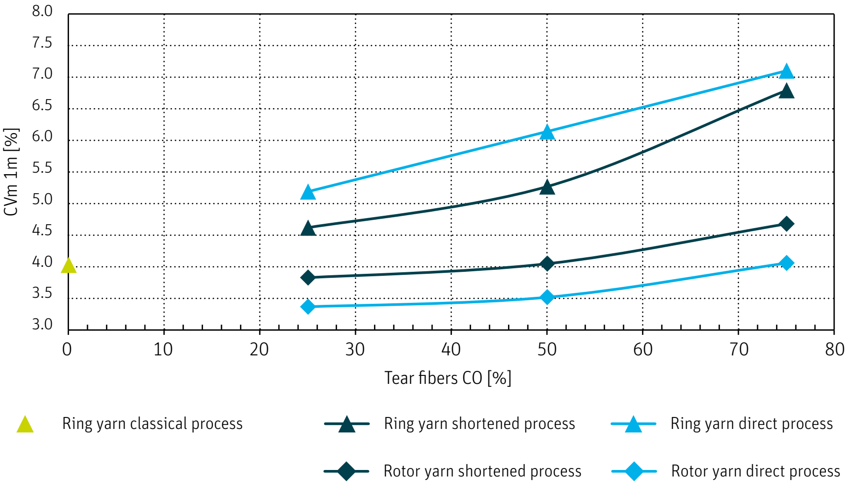


Fig. 32: Both rotor spinning processes show acceptable values also with high tear fiber content.

Source: TIS 28178 / Technology & Process Analytics

Unevenness on Ring and Rotor Yarn

Virgin CO 29.7mm, 4.1 Mic/Tear fibers CO, Ne 20, αe 4.7, Rotor 33-XT-BD

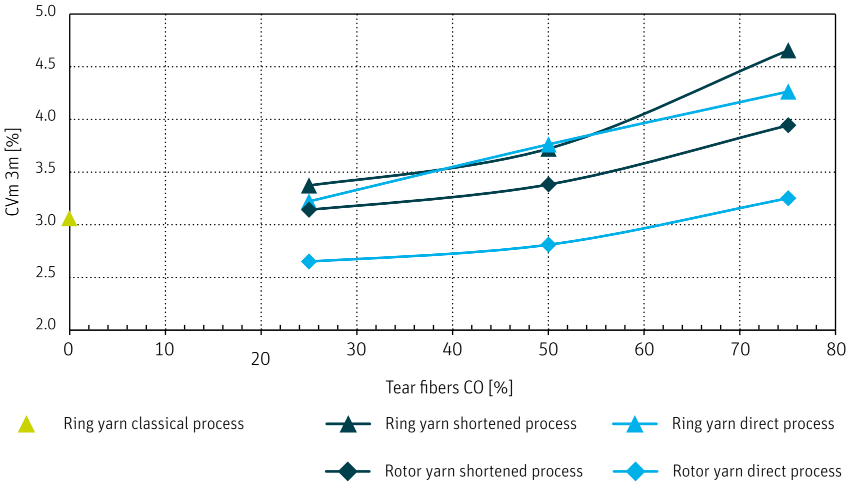


Fig. 33: The direct rotor spinning process with higher sliver adhesion length has a beneficial impact on the long-wave unevenness.

Source: TIS 28178 / Technology & Process Analytics

Unevenness on Ring and Rotor Yarn

Virgin CO 29.7mm, 4.1 Mic/Tear fibers CO, Ne 20, αe 4.7, Rotor 33-XT-BD

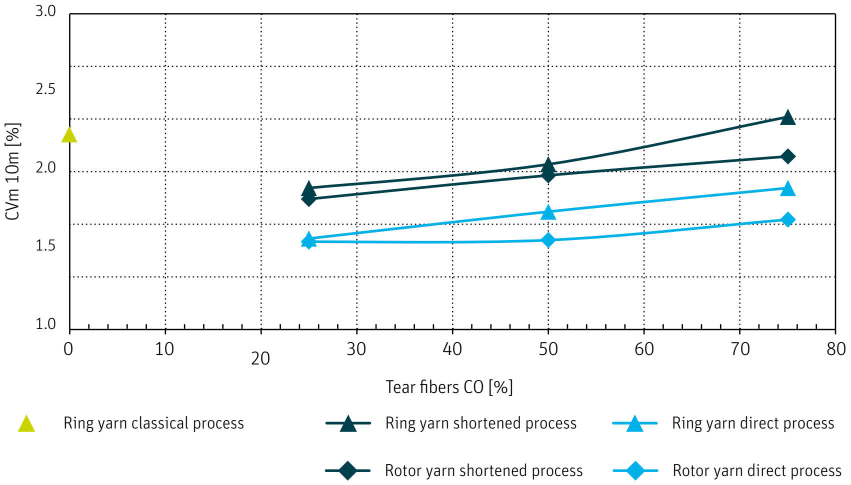


Fig. 34: The direct rotor spinning process reaches the best values here, too.

Source: TIS 28178 / Technology & Process Analytics

9.2. Neps

In addition to the advantages of the rotor spinning process over the ring spinning process in respect of fiber feeding, rotor spinning also offers the advantage of being able to extract fine fiber knots and trash particles with fibers from virgin cotton thanks to the opening roller and the extraction unit. This results in significantly lower nep values with the rotor spinning process compared to ring spinning as the recycled content percentage increases. The disadvantages of the ring spinning process increase disproportionately as the recycled content percentage increases and, in extreme cases, can be up to five times higher than with the rotor spinning process.

Neps on Ring and Rotor Yarn

Virgin CO 29.7mm, 4.1 Mic/Tear fibers CO, Ne 20, αe 4.7, Rotor 33-XT-BD

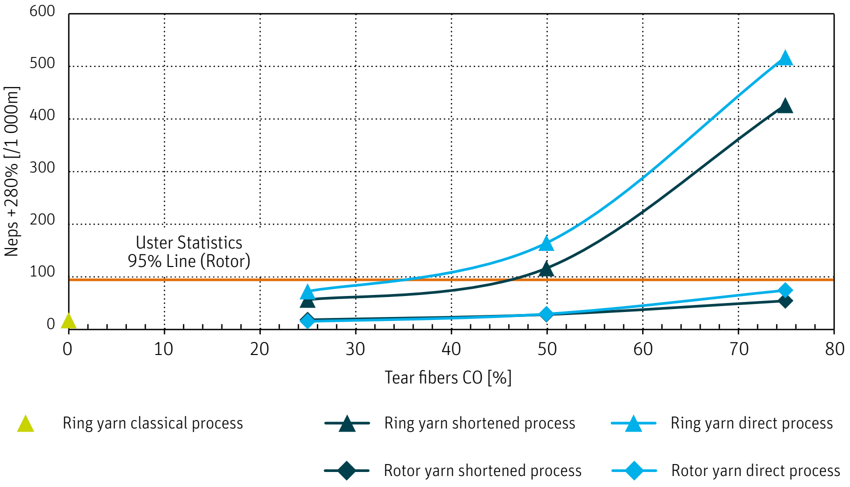


Fig. 35: Significantly lower neps in rotor spinning compared to ring spinning, especially when the recycled content increases.

Source: TIS 28178 / Technology & Process Analytics

9.3. Tenacity and Elongation

Due to the yarn structure and creation of fiber-fiber friction, spinning systems have a greater impact on yarn tenacity than the recycled content of the blend or fiber length characteristics. The ring spinning process therefore achieves significantly higher tenacities than rotor spinning. In both rotor spinning and ring spinning, yarn tenacity decreases in a linear relationship with the recycled content.

Breaking Tenacity on Ring and Rotor Yarn

Virgin CO 29.7mm, 4.1 Mic/Tear fibers CO, Ne 20, αe 4.7, Rotor 33-XT-BD

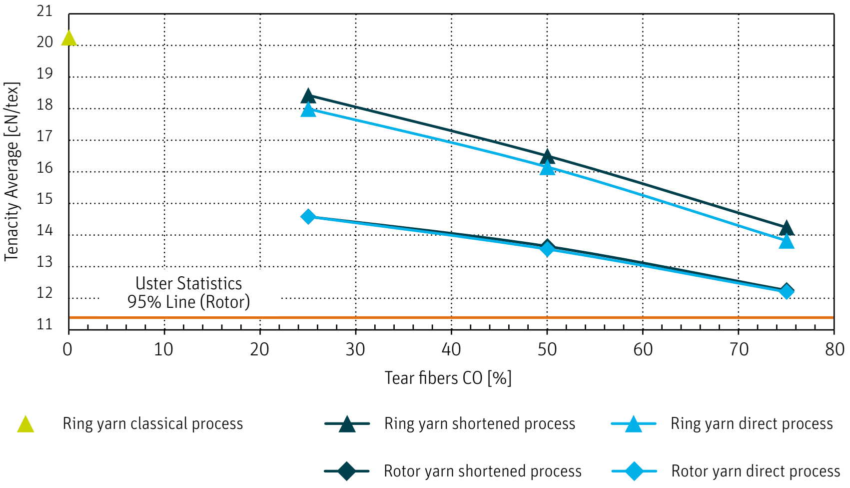


Fig. 36: Yarn structure and fiber-fiber-friction of the ring yarn significantly contribute to the high tenacity.

Source: TIS 28178 / Technology & Process Analytics

The tenacity requirements for the further processing of rotor yarns in the weaving mill are no longer met above a recycled content of 75%. To expand recycling applications in the future, it will therefore be essential to ensure that recycled raw materials can also be processed optimally using the ring spinning process in addition to non-woven fabric production and rotor spinning in the coarse yarn count range.

An additional advantage of the ring spinning process is much greater elongation. This significantly improves the working capacity of the yarns, thus opening up weaving mill applications.

Breaking Tenacity on Ring and Rotor Yarn

Virgin CO 29.7mm, 4.1 Mic/Tear fibers CO, Ne 20, αe 4.7, Rotor 33-XT-BD

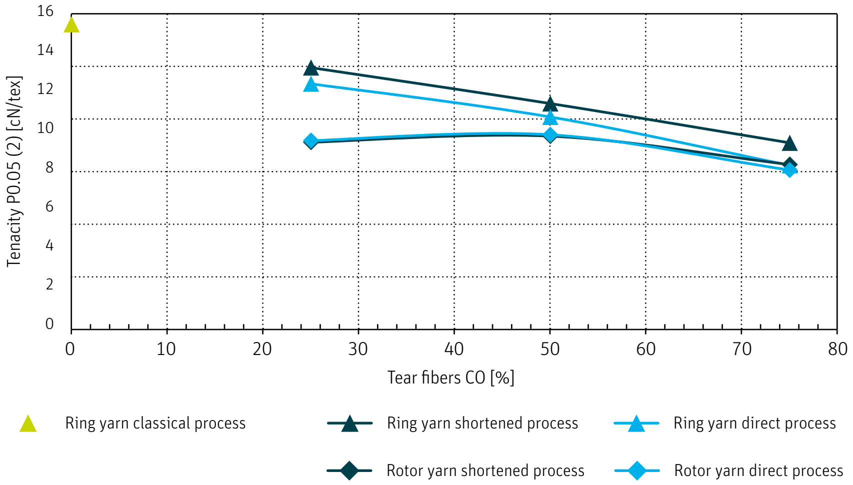


Fig. 37: The tenacity of the weak points in the yarn are between 8 and 14 cN/tex.

Source: TIS 28178 / Technology & Process Analytics

Breaking Elongation on Ring and Rotor Yarn

Virgin CO 29.7mm, 4.1 Mic/Tear fibers CO, Ne 20, αe 4.7, Rotor 33-XT-BD

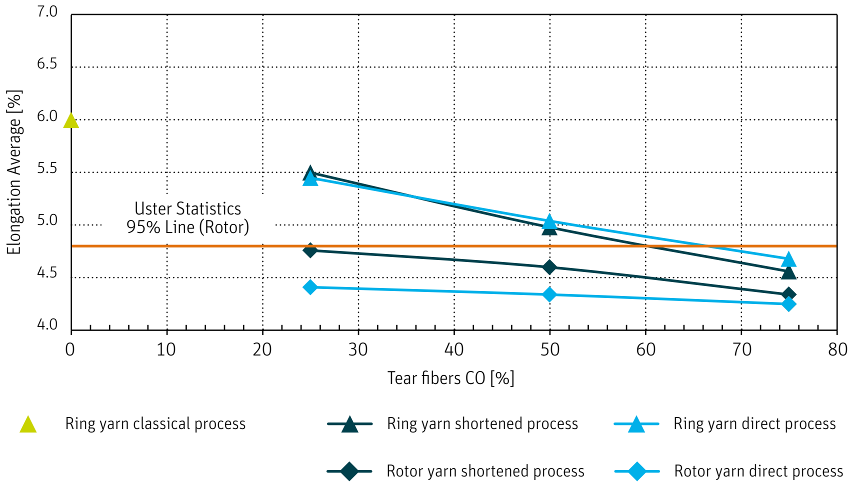


Fig. 38: With the ring spinning process a much greater elongation was reached.

Source: TIS 28178 / Technology & Process Analytics

9.4. Hairiness and Abrasion

Hairiness is influenced primarily by the yarn structure in the end-spinning process. Rotor yarns generally exhibit less hairiness than ring yarns, bringing advantages for further processing and in the final product (e.g. in terms of the pilling characteristics.) Hairiness and abrasion are also influenced by the recycled fiber content in the blend. As the blend ratio and therefore short-fiber content increases, so do hairiness and abrasion.

Hairiness on Ring and Rotor Yarn

Virgin CO 29.7mm, 4.1 Mic/Tear fibers CO, Ne 20, αe 4.7, Rotor 33-XT-BD

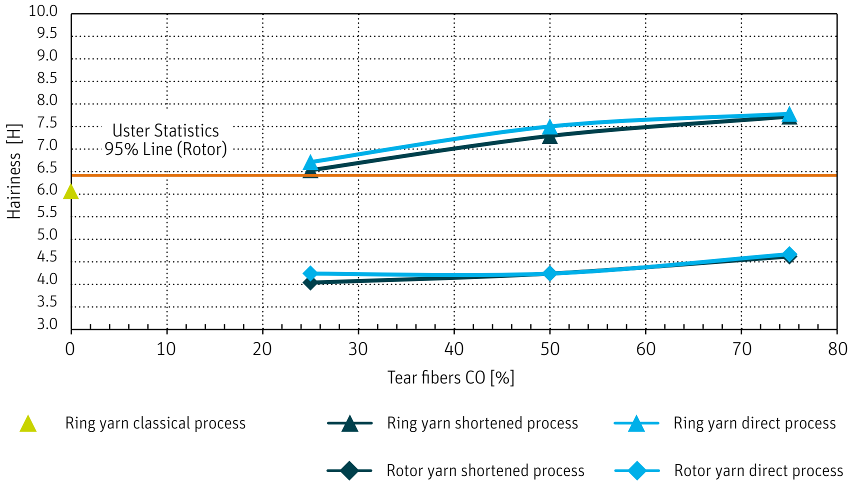


Fig. 39: Due to its yarn structure, rotor yarns generally exhibit a lower hairiness than ring yarns, what is also valid here.

Source: TIS 28178 / Technology & Process Analytics

Abrasion on Ring and Rotor Yarn

Virgin CO 29.7mm, 4.1 Mic/Tear fibers CO, Ne 20, αe 4.7, Rotor 33-XT-BD

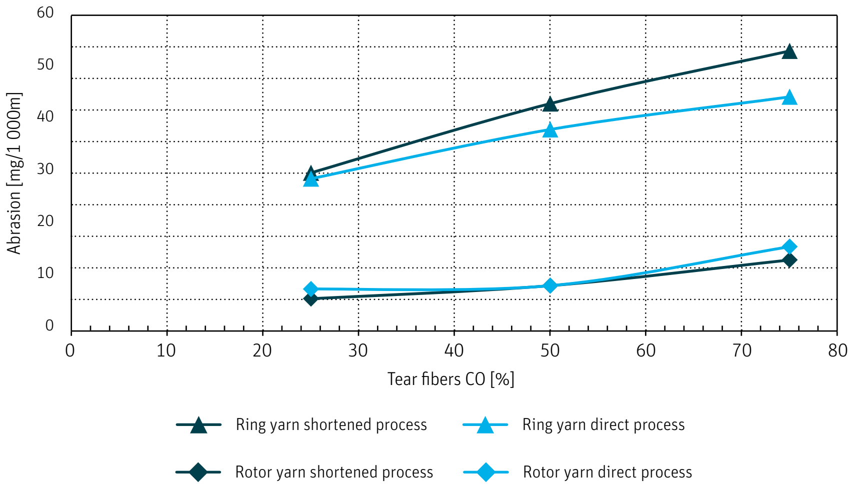


Fig. 40: Lower hairiness means lower abrasion, a positive aspect for rotor yarns.

Source: TIS 28178 / Technology & Process Analytics

10. Fabrics

10.1. Pilling Performance

Pilling performance of the recycled raw material is equivalent to that of the virgin raw material. This can be attributed to the fact that the shorter staple of the recycled fiber gives it a higher stiffness, making it less prone to pilling than a longer fiber. Thus, the slenderness of the fiber has a greater influence on the pilling characteristics than the short-fiber content. This means that the pilling characteristics of recycling fibers were no worse than the virgin cotton used, despite a higher short-fiber content and therefore increased hairiness.

Yarn structure clearly has a greater influence. It is apparent that, as usual, rotor yarn achieves better pilling values than a ring yarn. Only the production of a twin yarn produces equivalent pilling characteristics to rotor yarn.

Pilling Values on Ring and Rotor Yarn

Virgin CO 29.7mm, 4.1 Mic/Tear fibers CO, Ne 20, αe 4.7, Rotor 33-XT-BD

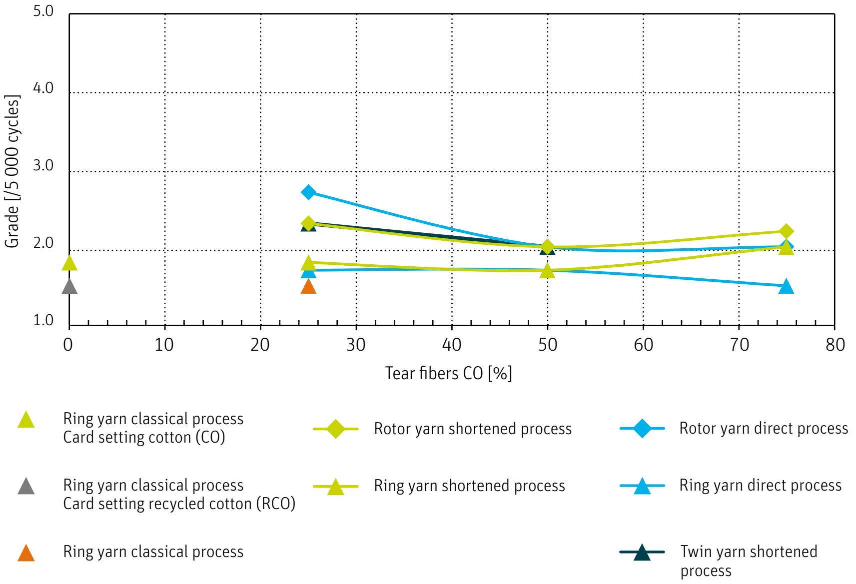


Fig. 41: The pilling performance of yarns with recycling fibers is equivalent to yarns from virgin cotton.

Source: TIS 28178 / Technology & Process Analytics

10.2. Optical Effect in the Fabric

As the proportion of recycled fibers increases, the result is a lighter-colored woven or knitted fabric since the tear fibers are bleached. The better yarn unevenness on the rotor yarn compared to the ring yarn is clearly reflected in the fabrics.

The opening roller unit on the rotor spinning machine has an additional positive effect. The fabrics produced from the rotor yarn contain significantly fewer fine trash particles. These trash particles, which are produced by the addition of virgin cotton or were not separated out via the blowroom, are efficiently separated out on the rotor spinning machine by the opening roller.

Fig. 42: The better yarn unevenness on the rotor yarn compared to the ring yarn is clearly reflected fabrics.

Source: TIS 28178/Technology & Process Analytics

10.3. Application

Due to good pilling values and positive optical characteristics in the fabric, the following applications are realistic:

Fig. 43: Denim and Workwear

Source: Kipas TR 100% recycled cotton

Fig. 44: T-Shirts

Source: ECOALF 60% virgin cotton 40% recycled cotton

11. Process Recommendation

We can derive the process steps, from fiber preparation through to the ring and rotor yarn, from the results obtained with the intermediate product, the yarn, and the fabric.

The fiber opening process must include

- Bale opening
- Fiber opening and removal of fabric pieces
- Dosing for the blend components
- One or two “long-term blends”, depending on customer requirements, to achieve sufficient homogeneity in the recycled component

This results in several options for fiber preparation within the blowroom line VARIOline. The downstream process sequence can either produce ring yarn or rotor yarn, depending on the final product requirements, with two different process sequence options for the rotor yarn: the direct process and the shortened process.

Process Recommendation for Fiber Preparation

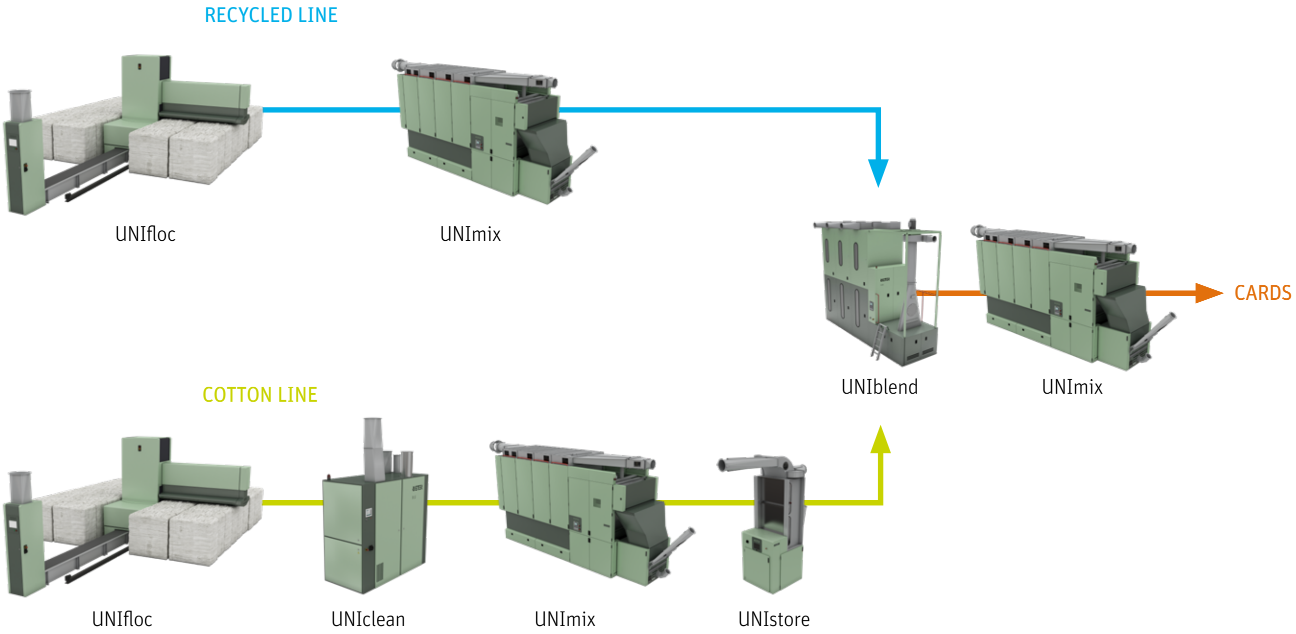
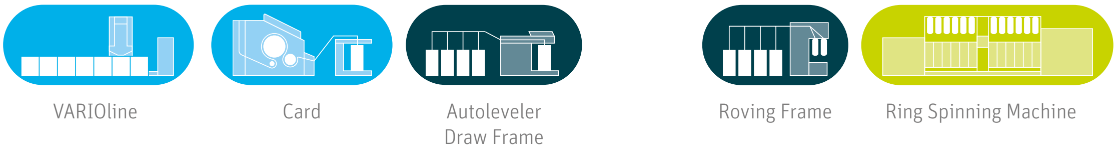


Fig. 45: For fiber preparation this is one possible set-up.

Process Recommendation for Spinning Recycled Raw Material

Ring spinning – Recycling cotton in blends with virgin cotton or polyester



Rotor spinning – Recycling cotton in blends with virgin cotton or polyester

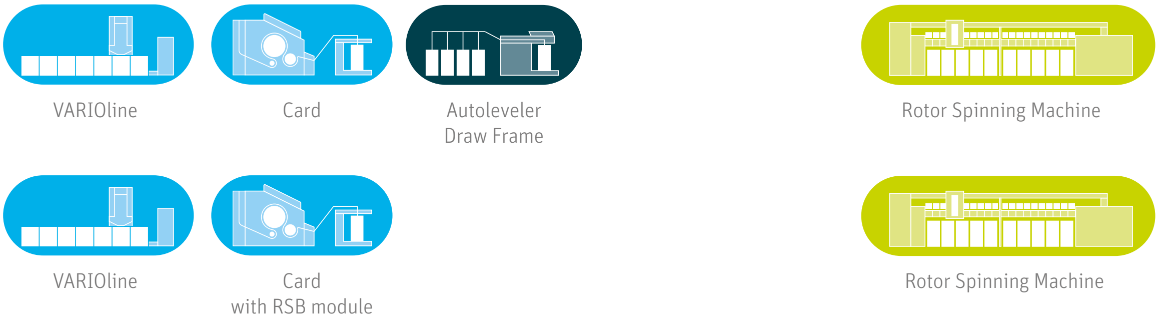


Fig. 46: To spin tear fibers in blends with virgin cotton one process for ring spinning and two processes for rotor spinning are recommended.

Source: Technology & Process Analytics

12. Economic Viability

In the application case using a yarn count between Ne 12 and 20, the yarn conversion costs are calculated for ring yarns and rotor yarns in Turkey.

If only the yarn conversion costs are taken into account, waste is higher in the processing of post-consumer material than virgin cotton raw material owing to the number of non-open pieces of fabric. Waste in the staple-fiber spinning process increases with a higher recycled content. Naturally, the yarn conversion costs are valid only if the pieces of fabric are not broken down during tearing or the staple-fiber spinning process. In the pre-consumer material application case, for example, this consideration does not apply because the waste is equal to or lower than with the use of virgin cotton raw material. The extraction of pieces of fabric or trash does not apply here.

As expected, yarn conversion costs for ring yarns are up to 0.3 cent/kg higher than for rotor yarn (Fig. 47).

Comparison of Costs in Turkey

Virgin CO 29.7mm, 4.1 Mic/Tear fibers CO, αe 4.7

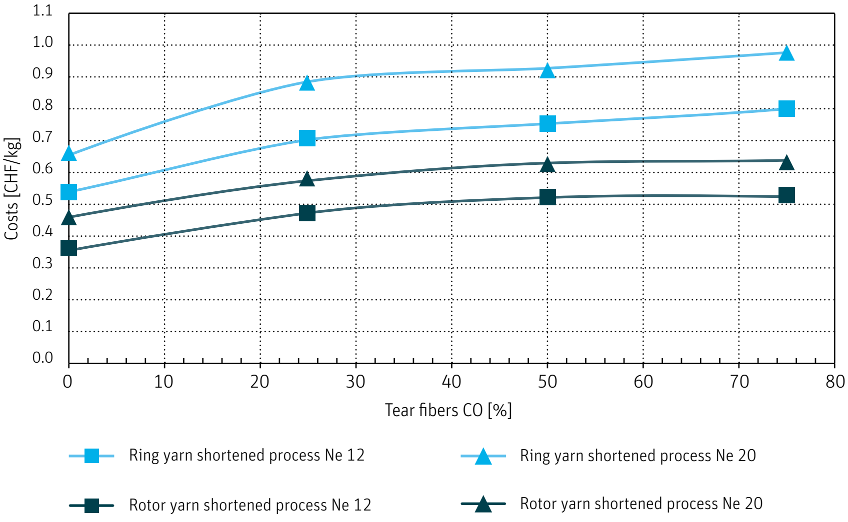


Fig. 47: As expected, yarn conversion costs for ring yarns are up to 0.3 cent/kg higher than for rotor yarn.

Source: TIS 28178 / Technology & Process Analytics

Alongside yarn conversion costs, another important factor in the economic analysis is return on investment, which also takes the price of the raw material and the yarn sale price into account (Fig. 48). Blending and processing recycled raw materials offers interesting and very good opportunities for the economic success of the staple-fiber spinning process.

The economic analysis is based on the assumption of a slightly cheaper recycled raw material price compared to a medium-quality virgin cotton and a commercial staple of 1 1/8 inches with a short-fiber content of < 26%. The calculation is also based on the realistic view that trade will be prepared to accept a higher price for only a negligible reduction in yarn or fabric quality to achieve better global use of raw material resources and better sustainability.

It should therefore be considered realistic for a blend containing 25 – 50% recycled raw material to increase the yarn sale price by at least 0.1 – 0.2 cent/kg, depending on the end-spinning process and yarn count (Fig. 49).

A blend containing 75% recycled material results in a disproportionate reduction in yarn quality, meaning that a yarn sale price that is lower than or equivalent to virgin cotton raw material is to be expected accordingly. The result in this case would be a return on investment that rises again in years for the staple fiber yarn producer.

There will be greater or lesser scope for the economic viability of the staple-fiber yarn production process depending on whether it is a case of yarn trading or a fully integrated process. In any case, the economic analysis shows interesting possibilities and opportunities for processing recycled cotton raw materials using staple-fiber yarn production.

Return on Investment in Turkey

Virgin CO 29.7mm, 4.1 Mic/Tear fibers CO, αe 4.7

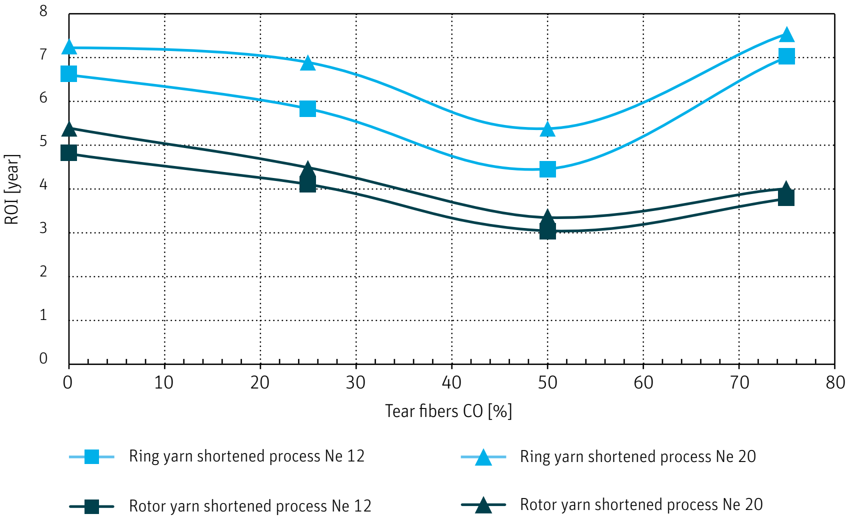


Fig. 48: The economic analysis shows interesting opportunities for processing recycled cotton raw materials.

Source: 28178/Technology & Process Analytics

Yarn Price in Turkey

Virgin CO 29.7mm, 4.1 Mic/Tear fibers CO, αe 4.7

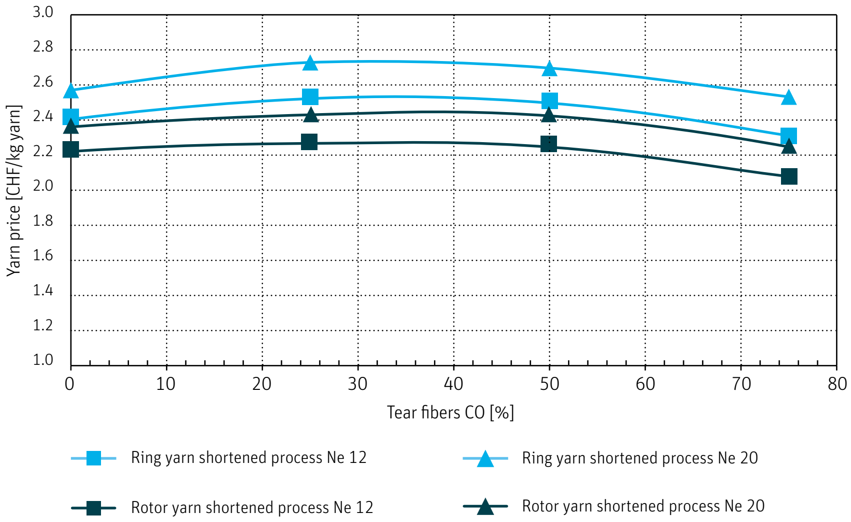


Fig. 49: It should be realistic to increase the yarn sale price by at least 0.1 – 0.2 cent/kg for a blend containing 25 – 50% recycled raw material.

Source: TIS 28178/Technology & Process Analytics

13. Conclusion

In recent years, better use of raw materials has become very important in the textile sector due to growing environmental awareness, legal requirements for more sustainability, and the cost of raw materials. As a result, more research and development is being carried out in the various areas of raw-material recycling.

Requirements and key figures for the mechanical opening of post-consumer material must be defined for each industrial sector. The "Degree of Fabric Opening," "Efficiency of Fiber Opening," and "Fiber Length Characteristics" are examples that have been defined and classified in this study.
Coordination and cooperation between the different industrial sectors, from the procurement of raw materials through to the new final product, will also be vital. Only then will it be possible to expand and optimize the entire recycling process to help it grow into a larger market. In the next few years, quantities are expected to amount to at least 7.5 million tons per year if the current trend continues.

The object of this study are recycled post-consumer final products (tear fibers) blended with an average 1 1/8 inch African cotton in various blends. The study successfully demonstrated that the staple-fiber spinning process does not cause any further fiber shortening with optimal processing. However, process sequence adjustments, machine modifications, and setting adjustments are required for almost all process steps.

For acceptable yarn quality and operational reliability, a blend containing up to 75% recycled content is possible in this raw material configuration.

Rotor yarn has the best unevenness due to the closed fiber transport within the fiber feed channel and fiber doubling in the rotor with a high short-fiber content (> 30%). There are two options for the fiber preparation process, depending on the yarn quality requirements: the direct process and the shortened process.

Ring yarn, by contrast, has the highest yarn tenacity on account of more intensive fiber integration. This opens up a wider range of applications, namely the increased use of these yarns in weaving mills. In the case of ring yarns, the production of twin yarns on the compact-spinning machine allows yarn tenacity to be increased in blends with a tear fiber content of up to 50% and also allows unevenness to be improved.

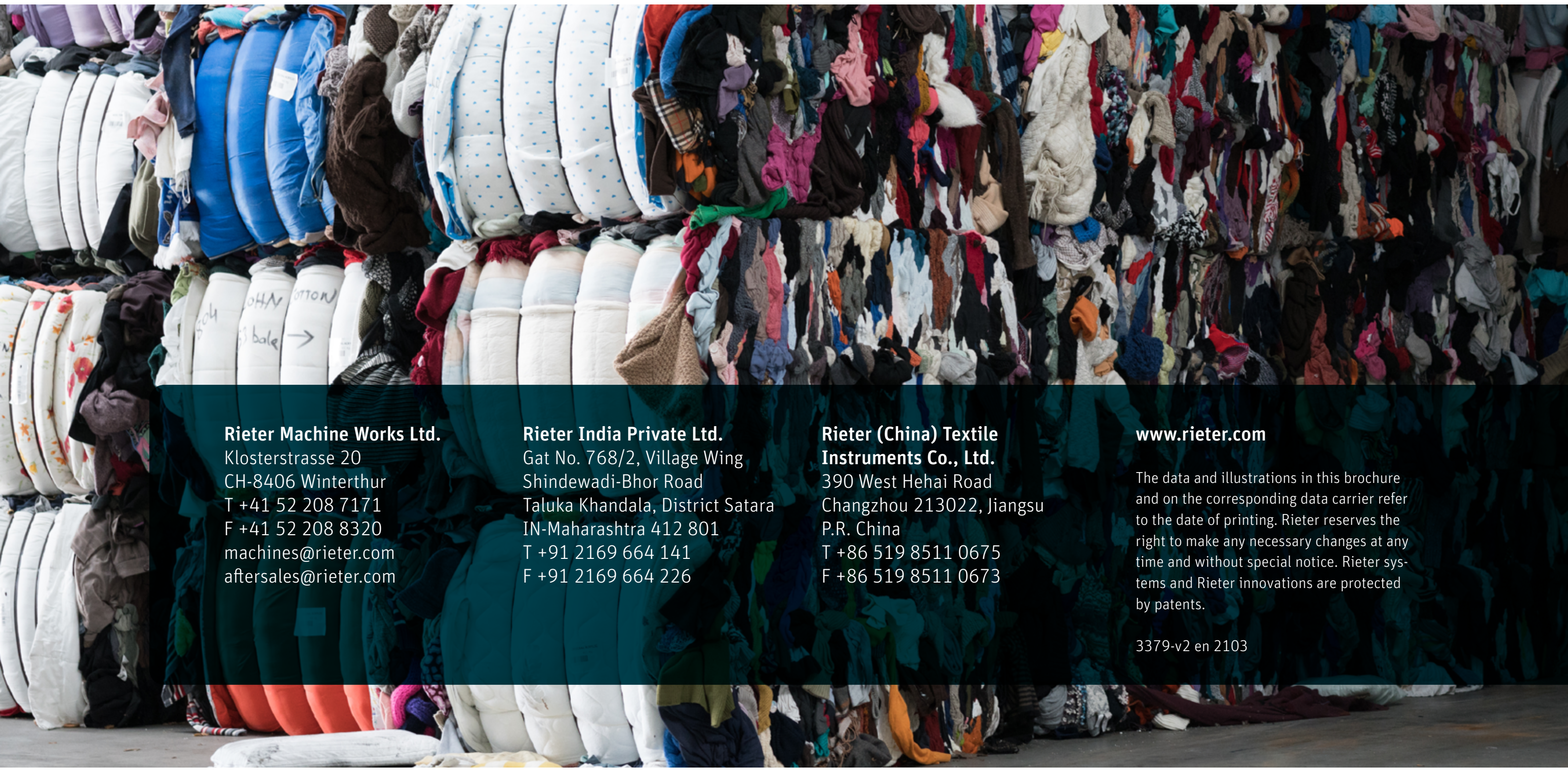
Pilling performance of the recycled raw material is equivalent to that of the virgin raw material. This is attributed to the higher fiber stiffness and low slenderness. The fibers either do not knot or, at most, only fall out of the yarn formation, but do not result in increased pilling as would have been expected on account of the higher hairiness. Even under these conditions, rotor yarn still demonstrates better pilling characteristics than ring yarn. Only a multi-component ring yarn like the twin yarn achieves the same good pilling values as a rotor yarn.

The spinning plan parameters achieved can be summarized as follows.

Blends with Tear Fibers and Virgin Cotton

Tear fibers (75%) with virgin cotton 1 1/8 inch (25%)	
Card production [kg/h]	80
Twist factor roving [ae]	2.3
Spin limitation for ring yarn and rotor yarn [Ne]	20
Twist factor for ring yarn and rotor yarn [ae]	4.7

Today, a blend with up to 75% recycled content (rotor) and 60% recycled content (ring) is economically viable.



Rieter Machine Works Ltd.
Klosterstrasse 20
CH-8406 Winterthur
T +41 52 208 7171
F +41 52 208 8320
machines@rieter.com
aftersales@rieter.com

Rieter India Private Ltd.
Gat No. 768/2, Village Wing
Shindewadi-Bhor Road
Taluka Khandala, District Satara
IN-Maharashtra 412 801
T +91 2169 664 141
F +91 2169 664 226

Rieter (China) Textile Instruments Co., Ltd.
390 West Hehai Road
Changzhou 213022, Jiangsu
P.R. China
T +86 519 8511 0675
F +86 519 8511 0673

www.rieter.com

3379-v2 en 2103