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Enhancing Recycled Ring Yarn Quality: Unlocking the Potential of Recycled Cotton Blends with the Combed Process

Contents

1. Introduction

Since the publication of the Rieter special print “The Increasing Importance of Recycling in the Staple-Fiber Spinning Process” three years ago, the interest in using recycled fibers for the textile production has further increased. While the chemical recycling industry, with its promise of virgin-like fiber quality, is in the process of scaling up, mechanically recycled fibers, mainly from post-industrial origin, are widely available for the spinning industry.

In terms of spinning technology, rotor spinning remains the dominant technology, while more and more companies are looking to extend the application range to ring and compact spinning.

Blending the recycled fibers with cotton or polyester (PES) remain popular options, with increasing interest in using man-made cellulosic fibers (MMCF).

This report focuses on a new approach of spinning ring/compact yarns from blends of mechanically recycled cotton and virgin cotton.

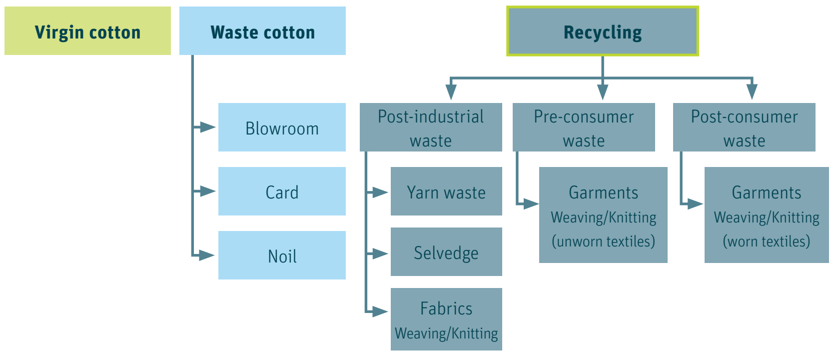


Fig. 1: Recycling classification

2. Determination of Mechanically Recycled Fiber Quality

2.1. Quality of mechanically recycled fibers

Specific legislation has been introduced over the last years, such as the European Union's "European Green Deal" or the United Nation's "Fashion Industry Charter for Climate Action". As a result, many fashion brands increase their efforts to source more environmentally friendly yarns in the upcoming years. It is clear that recylced fibers are going to play an important role in the fiber mix of the future and, as a result, numerous innovation projects are launched to deal with certain aspects of this raw material group. Altough, the quality of mechanically recylced fibers improved over the last years, they are still challenging to be re-spun into yarns, due to the following three reasons:

- remaining yarn and fabric pieces (opening degree),
- high short-fiber content (SFC) and
- high number of neps.

The dependency between the opening degree and the SFC is clear and well documented. How well the fibers can be opened on the tearing machine is influenced by many parameters: type of garment, fabric construction, dyeing and finishing process, raw material composition, to name a few from the material side. The process set-up and machine settings of the tearing line also play a role. Yarn waste, for example, yields longer fibers compared to woven post-consumer jeans, because it takes much more mechanical force to open a woven structure than a single yarn.

Increasing the opening degree of a certain material will almost certainly affect the fiber length, since more intense opening is usually accompanied by an increase in fiber damage. New tearing machine designs with new setting possibilities and additional lubricants can decrease the fiber damage, but there will always be a negative effect on the fiber length during the tearing process. This means that mechanically recycled fibers will not reach the original length of the virgin fiber. For most applications, it is therefore necessary to blend the mechanically recycled fibers with longer fibers like virgin cotton, recycled PES, or MMCF.

Compared to the opening degree and the fiber length, the number of neps is not well investigated. But as this report will show, they play a major role in the yarn character of ring yarns. Much more research activities should therefore be put into the reduction of neps and the cleanliness of the material in general.

2.2. Rieter testing standard for mechanically recycled fibers

One big obstacle to determine the quality of mechanically recycled fibers is currently the lack of any testing standards. This makes it difficult to compare results from different sources and creates a lot of confusion for all involved stakeholders.

To better understand the quality range of mechanically recycled fibers in today's market, Rieter has defined an internal testing standard for this raw material type and is collecting all results in the Rieter Recycling Database.

The testing process itself consists of two steps. In a first step the material is cleaned from remaining yarn and fabric pieces by using the Shirley Trash Tester. Remaining yarn pieces are removed manually by the lab personnel before testing the fiber length.

The second step is the actual fiber testing on Uster AFIS. The AFIS is additionally measuring the nep count. Rieter is also cooperating with other partners, who are using the Textechno Fibrotest and MDTA 4. These systems are widely used for the testing of mechanically recycled fibers.

While all testing devices show comparable trends, absolute values differ widely. This is further complicated by the fact that often weight-based values (w) are shown, which have generally lower values, while Rieter always uses number-based values (n) in publications.

As said before, both points make comparing results from different sources very difficult if not impossible at the moment.

2.3. Rieter recycled fiber classification

Rieter is continuously testing mechanically recycled fiber samples and compiling the results in the Rieter Recycling Database to get an overview of the existing fiber quality.

The following charts show the results of mechanically recycled fibers from post-industrial origin.

Special focus is put on the fiber length – here especially the SFC – and the neps. Comparing the SFC(n) of the fibers with the Rieter classification, only a quarter of samples can reach good quality, while most samples have a SFC in the medium to poor range (Fig. 3).

While there is a strong correlation of SFC and UQL (Upper Quarter Length) (an increasing number of short fibers also means the absence of longer fibers in general), none such correlation can be found between the number of neps and the UQL. It can also be seen that the number of neps shows a very big variation from below 200 to over 2000 with a mean value of around 650 (Fig. 4). This could indicate that the root cause for the creation of neps differs from the creation of short fibers.

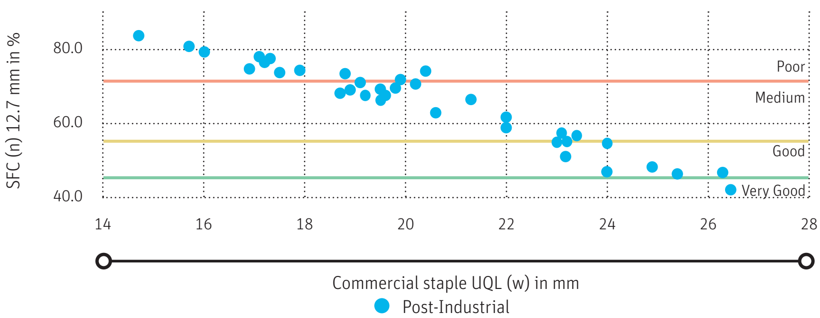
As the number of neps in the recycled fibers is a key factor that determines the final yarn character, the Rieter Recycled Fiber Classification (Fig. 2) is now extended by the nep count. It shows that the current situation in terms of neps is similar to the SFC, and around 75% of the tested samples fall into the category “medium” and “poor”. The reason for the high nep count and how it can be avoided urgently needs more research focus.

The Rieter recycled fiber classification

Fiber key parameters	Short-fiber content (n)	Mean fiber length (n)	Long fiber 5% (n)	Neps (1/g)
Cotton short staple (<1 1/8" as reference)	24%	21 mm	34 mm	150
Very good	< 45%	> 17 mm	> 31 mm	< 300
Good	< 55%	> 15 mm	> 27 mm	< 600
Medium	< 70%	> 12 mm	> 23 mm	< 900
Poor	> 70%	< 12 mm	< 23 mm	> 900

Fig. 2: The Rieter Recycled Fiber Classification helps spinners to find the right raw material for their demands.

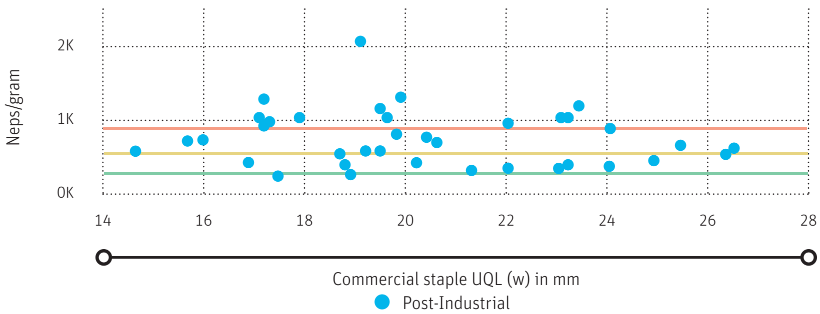
Uster AFIS Short-fiber content by number



46%	56%	68%	74%	80%
5% Quantile SFC	25% Quantile SFC	50% Quantile SFC	75% Quantile SFC	95% Quantile SFC

Fig. 3: Most fiber samples have a high short-fiber content and are rated medium or poor in the Rieter Recycled Fiber Classification.

Uster AFIS Neps content per gram



200	360	650	990	1 400
5% Quantile Neps	25% Quantile Neps	50% Quantile Neps	75% Quantile Neps	95% Quantile Neps

Fig. 4: This graph shows that the most recycled cotton (rCO) samples have too many neps and this topic needs more attention.

3. Combed Ring Yarn from Recycled Cotton Blends

3.1. Today's limitations

Ring spinning still is the most widespread spinning technology today, with a market share of around 60%. Therefore, it is not surprising that there is great interest in the use of mechanically recycled fibers in this application. However, there are certain limitations to the process, which makes the usage of mechanically recycled fibers challenging.

As discussed in the previous chapter, the two main reasons for this are the high SFC and the high number of neps.
The high number of short fibers in the material is difficult to handle during the many drafting stages of the ring spinning process. This causes high unevenness, thin/thick places, and low tenacity of the yarns.

In the normal carded ring process the neps can only be removed on the card. Depending on the nep size and the yarn count, the neps will be clearly visible in the yarn and give it a very "rustic" look and feel, almost similar to bast fiber yarns.

Both parameters become particularly problematic when virgin cotton is used as a blending fiber, which is often the case. Depending on the cotton quality, the virgin cotton can already have a high content of short fibers and neps. This can quickly limit the additional amount of recycled fibers that can be added to the blend. Today this limit can be seen at around 20% for carded ring yarns with a yarn count of Ne 30.

3.2. Possible impact of the combed process

Combing today is used to reduce the number of short fibers and neps for 100% virgin cotton. Using the combed process enables the spinning of finer yarns with a higher tenacity as well as lower imperfections and unevenness. It is a standard process, which is widely used in the industry. This quality improvement comes at a higher process cost: two additional process steps plus the removed short-fiber content (noil) of normally 14 – 18%.

With the potential of reducing the short-fiber content and the number of neps, it is a very interesting process to be also used for recycled cotton blends. As the combing process will surely improve the yarn quality, the focus is on how the recycled fibers will perform on the comber, how combing will affect the recycling ratio of the blend, and how the additional process steps and lower yarn realization is impacting the process cost. To answer this set of questions, Rieter cooperates with several project partners (Fig. 5) and conducted several internal trials in the Rieter SpinCenter in Winterthur as well as in the spinning mill of Rieter customer Polopiqué in Portugal and Ferre in Spain. This publication summarizes the results of these trials.

3.3. Project partners

For the trials, Rieter cooperated with key players of the recycling industry like spinners, recycled raw material suppliers, high-tech companies and academic researchers from leading European Universities.

Project stakeholders	Country	Position/Role	
Recover™	Spain	Recycled fiber producer/Supplier of all used recycled fibers	recover CIRCULAR FASHION FOR ALL
Ferre	Spain	Spinning mill/Rotor spinning of the comber noil	FERRE
University of Leeds	UK	University/Blend ratio analysis – establishing a mathematical modelling for estimation	UNIVERSITY OF LEEDS
Saxion University	Nether-lands	University/Blend ratio analysis of recycled material	SAXION UNIVERSITY OF APPLIED SCIENCES
Polopiqué	Portugal	Field trial customer/Vertical garment producer (spinning to fashion)	polopiqué
Tailorlux	Germany	Tracer fiber producer/Blend ratio analysis of recycled material	Tailorlux integrity solutions

Fig. 5: Project partners with whom Rieter worked together for the trials.

3.4. Trial questions

The trial questions were defined to determine the trial set-up and to define the most relevant topics and targets.

1. ***Which blending ratios of virgin and recycled cotton are most suitable to compare the combed and carded processes?***

As it is expected that more recycled fibers as virgin cotton fibers will be removed with the combed process, the trial design is adapted accordingly: the samples that are combed have a higher recycling share compared to the ones that will only be carded.

This means that for the carded process 75% virgin cotton is blended with 25% recycled fibers. The samples from the combed process have a 50%/50% share of virgin cotton and recycled fibers. The target is that in the end the recycling ratio of the combed samples remains much higher than in the 75/25% carded reference sample.

It is possible that the addition of many short fibers affects the running performance of the blend on the comber (unwinding of the laps) as well as after the comber (low sliver cohesion due to high fiber parallelization).

It is also important to understand how the higher SFC is affecting the noil level.

2. ***What is the impact of the combed process on the blending ratio?***

One main question of the trial is how many recycled fibers are removed during the combed process and how this is affecting the overall recycling ratio in the final yarn. For this, in particular the determination of the blending ratio in the final yarn is of fundamental importance. Chemical detection, as is done for polyester/cotton blends, for example, is not possible in this case as both blending materials (the recycled and virgin cotton) are of cellulosic origin.

Therefore, different methods are tested to determine the share of recycled fibers in the blend after different process steps (see chapter 6). One method is **color measurement**, where the comparison of the different color shades before and after a certain process step, can provide information about the change of the blend ratio between the virgin cotton and the colored recycled fibers.

Another method is the usage of **tracer fibers** in the recycled fibers. The change in concentration of the tracer fibers after each process can give an indication about the change in the blending ratio.

And the **noil level** itself can be an indication of how much recycled and virgin fibers are removed. For this purpose, the trial was conducted with four different blend ratios.

3. ***How does the combed process affect the yarn quality?***

The combed yarns must meet two requirements. They must have a higher share of recycled fibers compared to the carded samples and the yarn quality must be significantly better.

By removing the shortest fibers as well as many neps, the combed process is expected to achieve better yarn unevenness, imperfections, and dynamometric values, as well as better running performance on the ring spinning machines and the subsequent manufacturing steps.

4. ***How does the combed process affect the process cost?***

Achieving an improved yarn quality with a higher share of recycled fibers would be a great technological achievement, but it obviously comes with the cost of additional process steps and a higher process waste.

It is important to look at how the process costs are affected and estimate the additional margin for the yarns that is needed to make this process economically successful (see chapter 9).

4. Trial Set-Up

4.1. Raw material

The raw material for the blends of virgin cotton and recycled cotton has different properties (Fig. 6). The color difference makes it easier to determine the share of recycled fibers in the blend after the different process steps.

Raw material		Cotton	Recyling
Blend		100% CO	100% rCO
Origin		Chad	Recover
Commercial Staple; UQL (w)	mm	29.7	19.4
5% – fiber length (n)	mm	36.5	23.3
Mean fiber length L (n)	mm	18.9	10.3
Short-fiber content <12.7 mm (n)	%	29.5	69.1
Fiber Neps	1/g	197	1120
Seed Coat Neps	1/g	12	38

Fig. 6: Origin and properties of the raw materials used in the trials

4.2. Production processes

The processes below were used in the different trials (Fig. 7). The combed process includes two additional process steps: the combing preparation system and the comber. The noil resulting from the combed process is ideal for processing on a rotor spinning system.

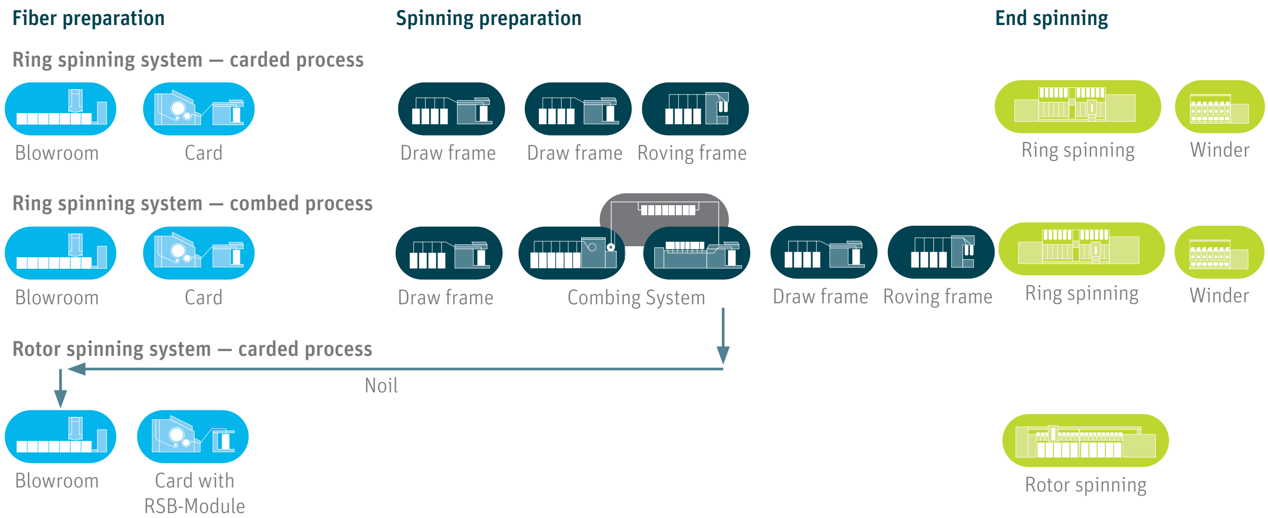


Fig. 7: The different blends were processed on the carded and combed ring spinning processes to determine the influence of combing.

4.3. Sample description

The experimental plan and the samples of the project are shown in the table below. Carded and combed production processes, different blending ratios, the comber settings are selected as trial parameters, see 5.2. To determine the influence of the combed process on recycled cotton fiber blends, a narrow to open detaching distance (L, M and H) was set on the comber.

Experimental plan	100% CO	75% CO/25% rCO	50% CO/50% rCO (L, M, H)
Process	Carded	Carded	Combed
Raw material 1	100% CO	75% CO	50% CO
Raw material 2	–	25% rCO	50% rCO
Raw material mix	Cotton	Cotton/recycle	Cotton/recycle
Yarn Ne	Ne 30	Ne 30	Ne 30

Fig. 8: Properties of the samples and process parameters

4.4. Spin plans

Carded ring process

Machine	Type	Infeed ktex, tex	Doublings	Draft	Output ktex, tex	Production speed m/min, rpm	Remarks
Card	C 70		1	1	7.0		70 kg/h
SB draw frame	SB-D 50	7.0	4	4.7	6.0	600 m/min	
RSB draw frame	RSB-D 50	6.0	4	4.7	5.1	550 m/min	
Roving	F 39	5.1	1	6.9	740		
Ring spinning	G 35	740.0	1	37.8	19.6	αe 4	Ne 30

Fig. 9: Spin plan and parameters of the carded ring process

Combed ring process

Machine	Type	Infeed ktex, tex	Doublings	Draft	Output ktex, tex	Production speed m/min, rpm	Remarks
Card	C 70		1	1	7.0		70 kg/h
SB draw frame	SB-D 40	7.0	3	4.2	5.0	600 m/min	
OMEGAlap	E 36	5.0	24	1.54	79.0	180 m/min	
Comber	E 90	79.0	8	14.27	6.0	550 npm	f.a. 5.2 mm
RSB draw frame	RSB-D 50	6.0	4	4.7	5.1	550 m/min	
Roving	F 39	5.1	1	6.9	740		
Ring spinning	G 35	740.0	1	37.8	19.6	αe 4	Ne 30

Fig. 10: Spin plan and parameters of the combed ring process

Carded rotor process

Machine	Type	Infeed ktex, tex	Doublings	Draft	Output ktex, tex	Production speed m/min, rpm	Remarks
Card (integrated drawframe)	–		1	1	6.0		40 kg/h
Rotor spinning	–	6.0	1	0.12	49.2	75 000	Ne 12
Rotor spinning	–	6.0	1	0.16	36.9	75 000	Ne 16

Fig. 11: Spin plan and parameters of the rotor process

5. Results

5.1. Fiber preparation

As described before, the main parameters to look out for are the short-fiber content and the number of neps.

By adding recycled fibers to the virgin cotton, the short-fiber content is increasing. The SFC(n) of the blend mainly determines the possibilities for further processing. Assessing the SFC of the blend in the carded sliver is therefore important to judge the possible application and yarn count range.

Based on multiple trials, Rieter recommends the following:

Limits of short fiber content (n) %:

< Ne 10	max. 40%
Ne 10 – 16	max. 35%
Ne 16 – 24	max. 30%
Ne 24 – 30	max. 27%

The results show that the 75% CO/25% rCO blend is already exceeding the recommended limit for the final yarn count of Ne 30. This underlines the limitation of adding mechanically recycled fibers to virgin cotton in dependence of the yarn count. The fact that cotton has already quite a significant number of short fibers confines the amount of recycled fibers that can be added.

Adding 50% of recycled fibers increases the SFC(n) so much, that only very coarse carded ring yarns (Ne 6 – 12) can be spun (Fig. 12).

Adding mechanically recycled fibers not only increases the SFC(n), but also the number of neps. Considering a constant nep removal efficiency on the card, this means that the nep count in the card sliver is also increasing (Fig. 13).

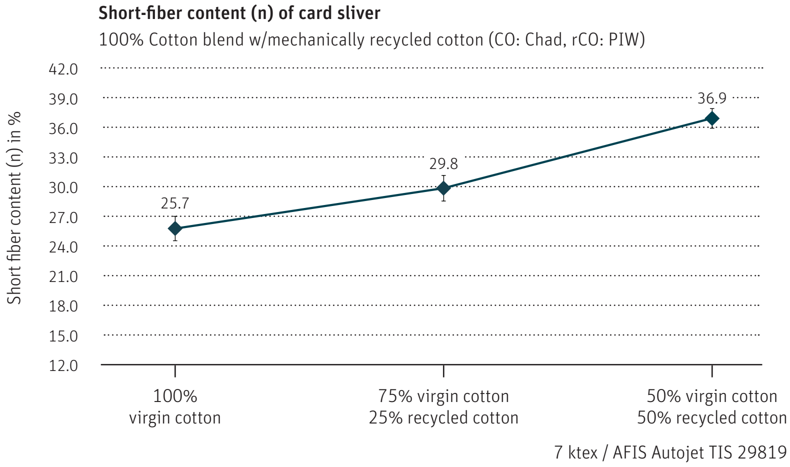


Fig. 12: The fact that also virgin cotton contains short fibers limits the share of recycled fibers (with a even higher short-fiber content) that can be added.

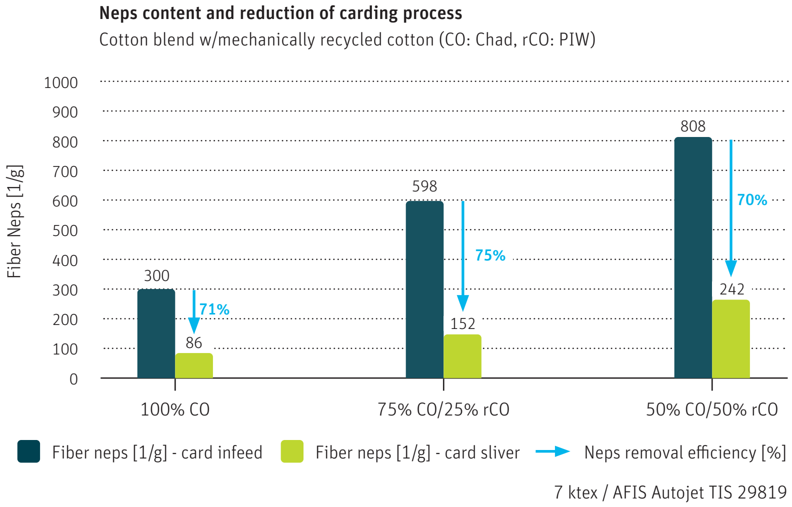


Fig. 13: The more recycled cotton is added to the blend, the higher is the number of neps.

Waste in blowroom and card

Keeping an eye on the waste level and with it the economic side of the process is as important as the technological figures and facts.

It becomes clear that especially the card waste is increasing with an increasing ratio of recycled fibers in the blend. The total amount of waste of the 50% CO/50% rCO sample is about 50% higher compared to 100% virgin cotton (Fig. 14).

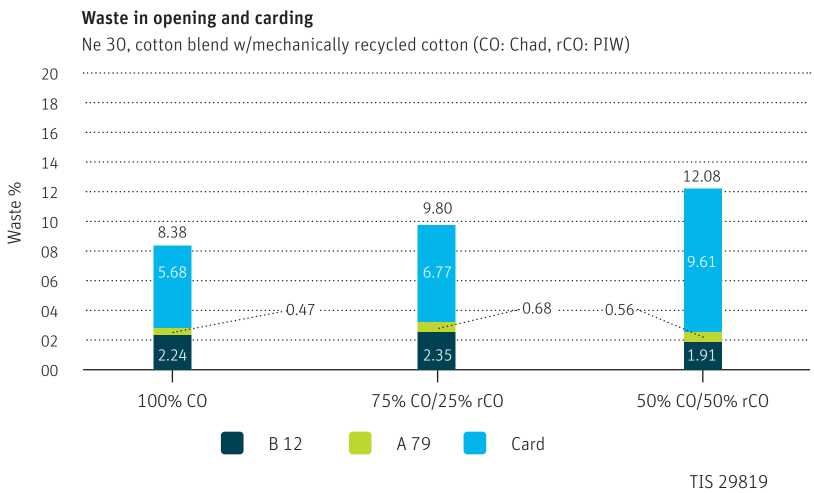


Fig. 14: Particularly the card waste is increasing with a higher share of recycled cotton.

5.2. Combing

5.2.1. Comber settings

To better understand the impact of combing on the various aspects of achievable quality, several different settings were tested on the comber.

Using the possibility of the narrower detaching distance in the E 90, a detaching distance of 7 mm **(M)** was chosen together with a standard setting of the top comb penetration of +0.5 and the circular comb nipper distance of 0.3 mm.

To see how the noil level and the respective yarn quality can be impacted by different settings, two additional samples were taken.

One with a wider detaching distance of 8 mm **(H)**, with the target to see how the yarn quality further improves at a higher noil level.

And another sample, where the detaching distance was even further reduced to 6.5 mm **(L)** to determine the minimum noil level and its impact on the resulting yarn quality.

As the combing process is reducing the recycling ratio, the amount of recycled fibers that are used in the process needs to be increased significantly. The different comber settings were therefore tested with a blend of 50% virgin cotton and 50% mechanically recycled fibers.

Experimental plan	**Samples**		
	L	M	H
Process	Combed		
Raw material 1	50% CO		
Raw material 2	50% rCO		
Raw material mix	Cotton/Recycle		
Comber settings	L	M	H
E 90 npm	600		
Top comb penetration	-	0.5	0.5
Distance nipper ciruclar comb	0.5	0.3	0.3
Detaching distance	6.5	7.0	8.0

Fig. 15: Properties of 50% CO/50% rCO samples and their process parameters.

5.2.2. Comber noil

The noil level increases with a higher recycling ratio. This is clear as more short fibers are present in the blend. From 100% cotton to the 50/50 blend the noil is increasing by around 80% with the same comber settings (M), from 14.3% to 25.9% (Fig. 16).

At the same time this already proves that most of the recycled fibers remain in the blend, as the noil level is still far too low to remove all of the recycled fibers plus the short fibers from the virgin cotton.

An additional 1.5% of noil can be saved by decreasing the detaching distance from 7.0 mm to 6.5 mm (L). The 24.4% can be considered as the minimum noil level for this particular raw material blend.

When the detaching distance is opened by 1 mm from 7.0 to 8.0 mm (H) the noil increases by 21% to 31.4%.

The additional impact on the overall waste level from blowroom to comber can be seen in the following chart (Fig. 17).

The combing process significantly increases the amount of material that is eliminated from the process (Fig. 17). While it may seem as a high material loss in the first place, this study is giving answers regarding ways to deal with the higher noil level (see chapter 8) and what impact it has on the economics (see chapter 9).

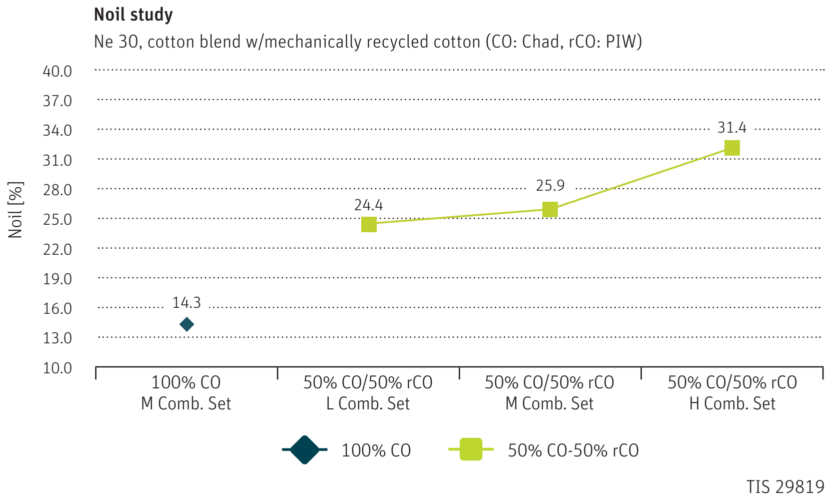


Fig. 16: The noil level is rising with more recycled fibers but it contains also short fibers from the virgin cotton.

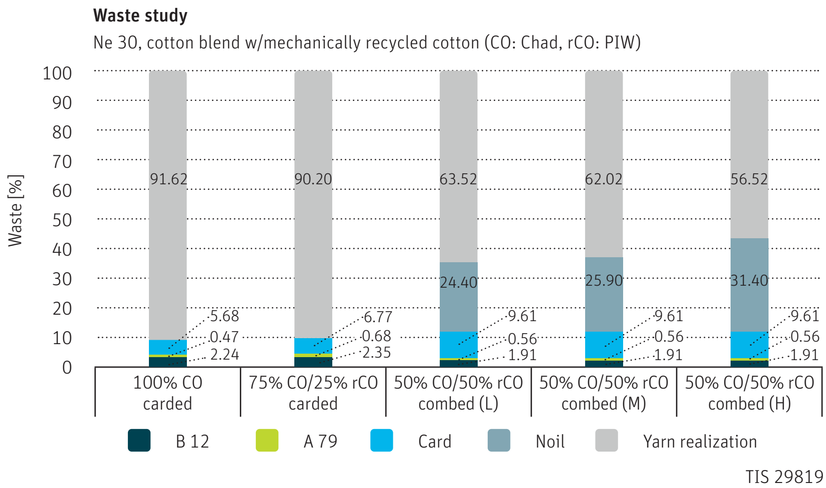


Fig. 17: Combing out the short fibers increases the amount of raw material removed from the process.

5.2.3. Optical assessment of slivers

As the used mechanically recycled fibers are black, the impact of different process steps can be clearly seen by the color change that results from a certain process step like combing.

As can be seen in the picture below – the color of the sliver changes depending on the blending ratio and the process steps involved.

The combed slivers clearly show that even after combing the color is darker compared to the carded sliver of the 75/25 blend (Fig. 18). This indicates that there is still a large amount of black, recycled fibers present.

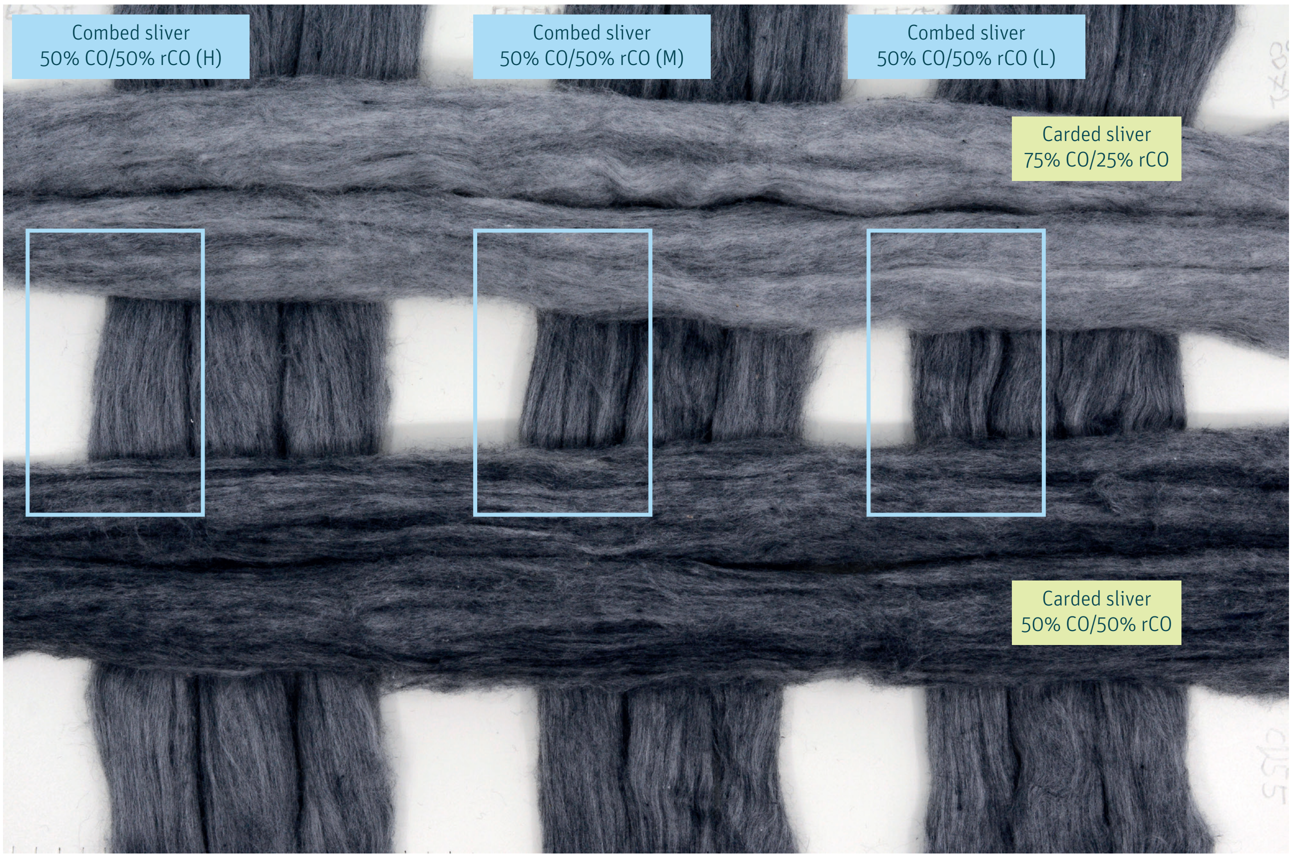


Fig. 18: Visual comparison of carded and combed slivers with different blending ratios.

5.2.4. Comber impressions

Fig. 19: Pictures of the combing section during the production of 50% CO/50% rCO combed ring yarn

5.3. Second draw frame passage

The final draw frame passage is the best process step to compare the different blends and to get a first idea of the impact of the combed process on the quality compared to the carded samples.

All combed samples have a lower SFC(n) compared to the 75/25 carded sample, while still having a higher recycling ratio. With the highest noil level due to the wider detaching distance of 8 mm in the comber (H) the SFC(n) is even comparable to the 100% cotton sample.

The combed process can also clearly improve the number of neps in the sliver. Compared to the carded 75/25 sample, all three combed samples show a lower amount of neps with a higher recycling ratio (Fig. 20).

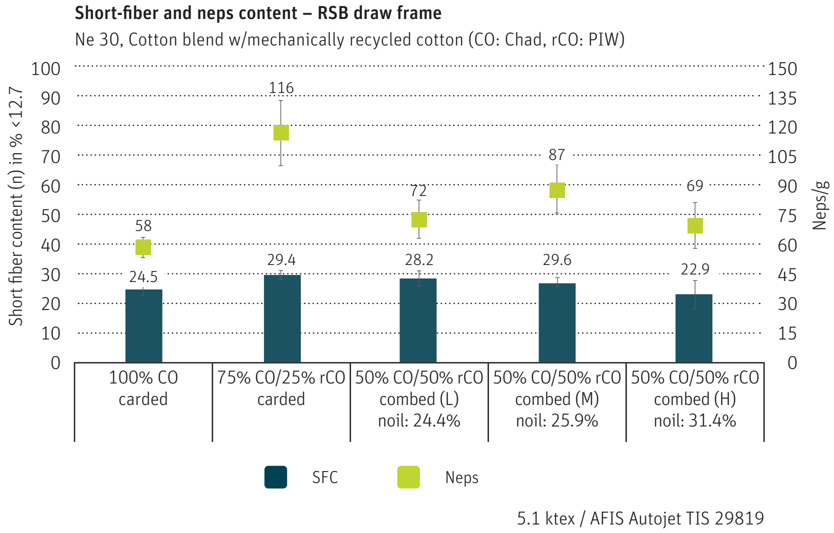


Fig. 20: Although the share of recycled fibers is higher in the combed samples, the short-fiber content and the number of neps is lower compared to the carded recycled sample.

5.4. Yarn

5.4.1. Yarn unevenness and imperfections

The yarn results clearly underline the impact of recycled fibers on the achievable yarn quality. When comparing the 100% virgin cotton carded sample to the 75/25 carded sample, the unevenness, the thick places and neps are clearly affected. Especially the neps and thick places increase by more than four times. This shows that the number of neps is an important parameter that needs to be controlled in mechanically recycled fibers.

Increasing the blend ratio to 50/50 and using an additional combing step, shows a very positive effect on the achievable yarn quality. All three combed samples show better results regarding unevenness and imperfection level, while having a recycling content that is almost double as high compared to the carded reference (Fig. 21).

These better yarn results are also reflected by an improved spinning efficiency with fewer yarn breaks and less fiber fly on the ring spinning machine.

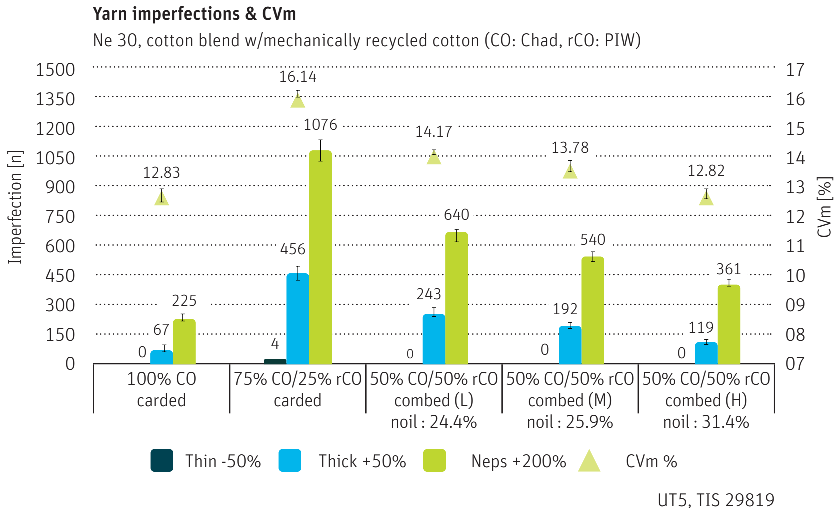


Fig. 21: Despite the higher share of recycled fibers in the combed samples, the yarn quality is better than in the carded samples.

5.4.2. Hairiness and abrasion

By removing the most disturbing short fibers, the hairiness and the abrasion of the yarns can also be significantly improved with the combed process.

The abrasion is clearly rising from 100% virgin cotton to the carded 75/25 sample (Fig. 22). Higher abrasion is one of the big challenges of recycled yarns in the downstream process, where higher fiber fly can lead to reduced machine efficiency and faults in the fabric.

While the recycling ratio is higher in the combed yarn samples, the abrasion can be clearly reduced to almost the level of 100% virgin cotton, while the hairiness is even slightly better.

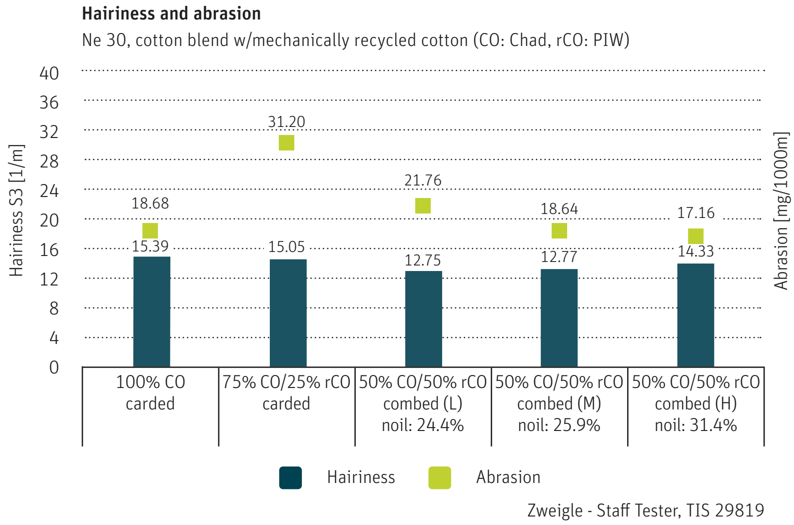


Fig. 22: Combing significantly reduces hairiness and abrasion in yarns containing mechanically recycled cotton.

5.4.3. Tenacity

A high amount of short fibers negatively affects the tenacity of the yarn. This can be clearly seen when comparing the 100% virgin cotton sample with the 75/25 carded sample (Fig. 23).

The combing process can more than compensate for an increase in the recycled fibers: even with the minimum noil level (L) the samples reach the same tenacity level as the 75/25 carded sample. However, the tenacity is still lower than the 100% virgin cotton sample.

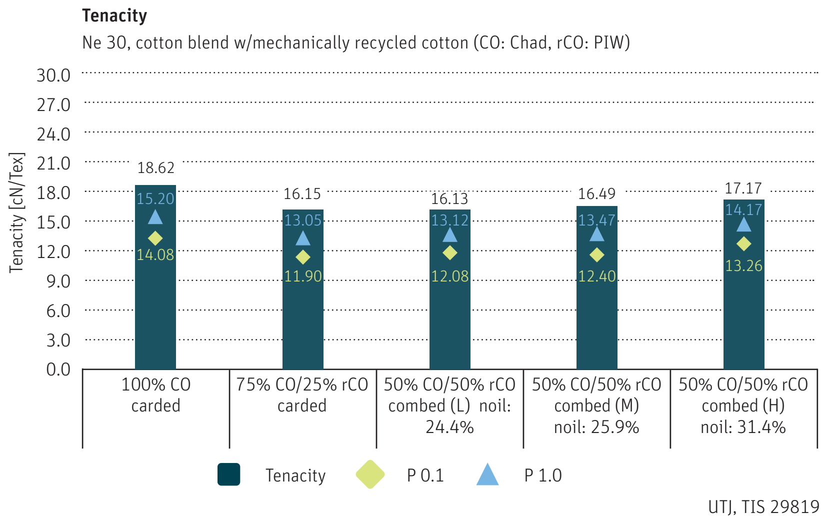


Fig. 23: Yarn tenacity is higher in the combed samples compared to the carded samples with a lower share of recycled fibers.

In order to increase the tenacity to the level of 100% virgin cotton, a compacting system, like the compacting device COMPACTdrum, can be used. Compacting helps to include more fibers into the yarn body to support higher strength.

With the help of COMPACTdrum, the 75/25 carded and the 50/50 combed sample can both reach the same tenacity level as the 100% virgin cotton carded sample.

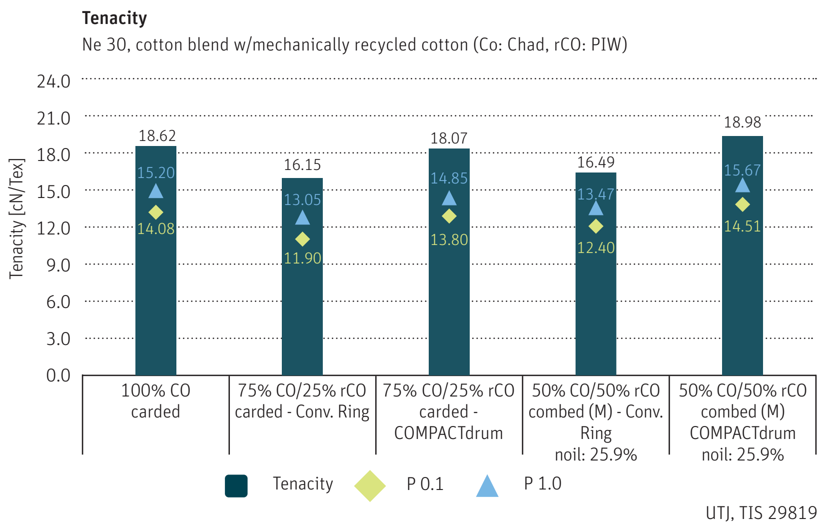
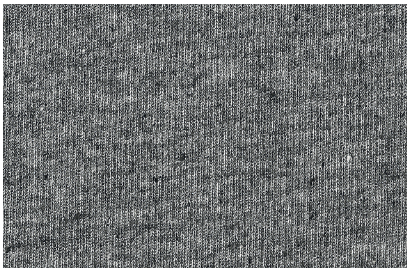


Fig. 24: The use of the compacting device COMPACTdrum for spinning recycled yarns brings tenacity to the level of 100% virgin cotton yarn.

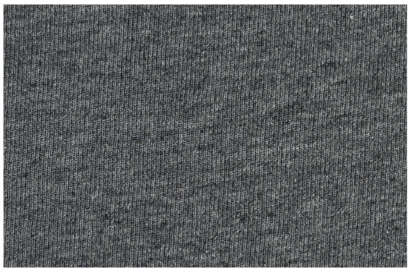
5.5. Fabrics

It is important to pay attention not only to yarn quality, but also to how the yarns behave in a fabric. All yarns were knitted into single jersey fabrics on a circular knitting machine. Even with the relatively small sample size it was evident that the combed samples had a better running performance with less dust creation and soiling.

The color difference between the carded and combed yarns is also visible in the fabric – the combed fabric is much darker, indicating a significantly higher recycling ratio (Fig. 25).



Single jersey, ring yarn, carded Ne 30
75% CO/ 25% rCO



Single jersey, ring yarn, combed Ne 30
50% CO/ 50% rCO

Fig. 25: The combed fabric is darker indicating a higher recycling ratio despite the combing out of short fibers.

6. Share of Recycled Fibers in the Yarn

As described earlier, three different options to determine the recycled content in the yarn were tested in this research project:

- color measurement by UV spectrophotometry,
- use of tracer fibers and
- calculation based on the noil level.

6.1. UV spectrophotometry

Thanks to the color difference between the used recycled cotton (black) and the virgin cotton, the color measurement method can be used to determine the blending ratio. Color measurements of end products (yarn) and intermediate process samples (sliver) were measured with a UV spectrophotometry device.

The base line (dotted) was determined by measuring hand blends (hand carding) at Leeds University from 100% black recycling (left) to 100% virgin cotton (right). The advantage of the process is that there is no waste during the carding process, which can lead to a distortion of the results.

The obtained L-values from color measurement were then analyzed with regression analysis to determine the blend ratio of recycled cotton.

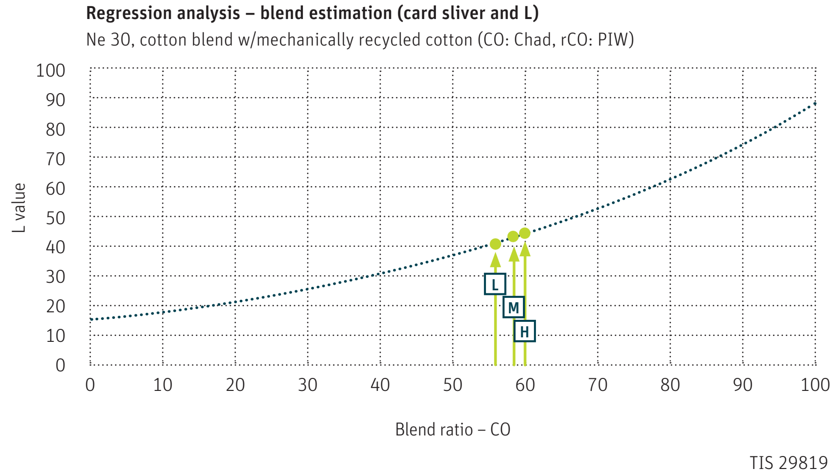


Fig. 26: The regression analysis shows that the ratio of virgin cotton increases depending on the setting in the comber.

The L-values of the finished yarns and fabrics indicate show how the virgin cotton ratio has changed over the spinning process. The virgin cotton ratio has increased for all three combed samples from 50% in the blowroom to 58 – 61% depending on the noil level:

- L-setting → 58% CO
- M-setting → 60% CO
- H-setting → 61% CO

It can be concluded that the equations derived from regression analysis and the method used provide an accurate blend estimation. It also shows that the process must be further developed, to improve the accuracy of the results.

A disadvantage of the method is that it only works for materials with a clear color difference and that for each material combination a new base line needs to be established, which is quite time consuming. While this method can be very helpful in showing the basics, more practical methods must be found that are suitable for a wider range of applications.

6.2. Tracer fibers

One of the most promising methods are tracers, either in form of a fiber or a spray. In this trial, tracer fibers were used, produced by Tailorlux, a German tracer fiber producer. Each batch of tracer fibers can be uniquely created individually for each fiber producer or product. The primary use case of these tracers today is to identify that a certain fiber type was used in a certain product. What is currently of secondary importance is to identify the blending ratio, but this will become much more important in the future.

Two main factors need to be considered for identifying the blend ratio. As the tracer fiber is blended with the recycled fibers, it also needs to behave like a recycled fiber and should therefore have the same length. If it is too long or too short, the impact of a certain process step will be overestimated or underestimated. Identifying the right length is therefore key.

The second important factor is that the tracer fiber must be blended as constantly as possible with the other fibers, as variation in the concentration will also lead to misleading results.

The results in this trial confirmed that this tracing technology has the potential to deliver on both requirements. But it was also obvious that the length and the blend consistency need to be further improved to get reliable results. More trials will be conducted to support the usability of this technology in the future.

6.3. Noil based calculation

The comber itself is an excellent fiber length measuring device, when used with a constant setting. The change in noil then clearly indicates a change in the SFC of the used material.

To better understand the impact of different blending ratios on the noil level, four different samples were compared, where the recycling ratio was increased from 0% to 75% in 25% steps. A 100% recycling sample was not possible due to missing fiber cohesion in the sliver and lap.

As can be seen in the chart the increase of the noil is linear with an increase of the recycling ratio. Based on the four sample points it can be assumed that the noil level for 100% recycled fibers would be around 42% (always based on this raw material and the same machine setting of the comber).

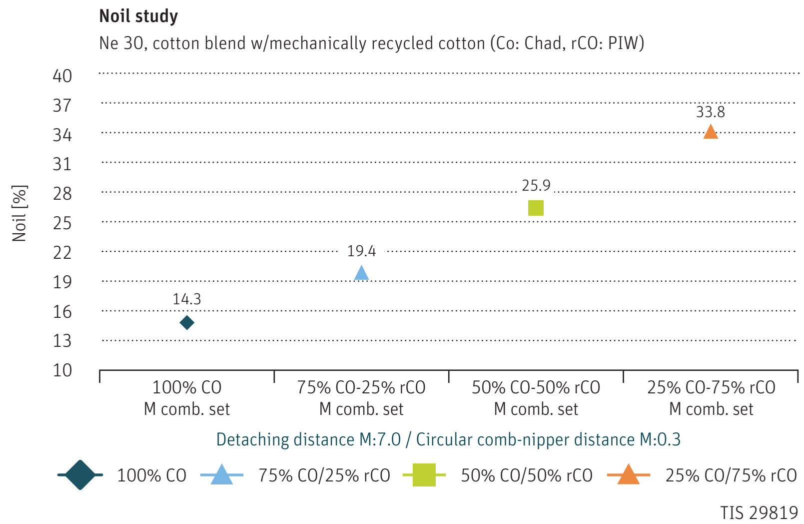


Fig. 27: The noil level increases linearly with the share of recycled fibers.

Based on the change in the noil level from blending ratio to blending ratio, the share of recycled fibers in the noil can be estimated.

The used virgin cotton has a noil level of 14.3 %. Let's assume this does not change in the 50/50 blend (with the same comber settings (M)). In this case around 7% of the 25.9% total noil is from virgin cotton. This is a bit more than one quarter of the total amount, which means that three quarters would be recycled fibers.

This result alters the blend ratio to around 40% of recycled fibers and 60% of virgin cotton after the combing process (see table). So, while the recycling ratio is reduced by the combing process, there is still a considerable amount of recycled fibers remaining in the blend.

Noil	Blend ratio	Calculated noil (%)	Estimated blend ratio (%)
CO	50.0%	14.3	60
rCO	50.0%	42.0	40

Fig. 28: Estimated blend ratio after the combing process compared to the original blend ratio.

7. External Trial at Customer Polopiqué

It is important to validate the combed process also on an industrial level and not only in the spinning laboratory. For this reason, a similar trial was conducted at Portuguese textile manufacturer Polopiqué, who already has longtime experience in using mechanically recycled fibers in cotton blends.

Raw material		**Cotton**	**Recycling**
Blend		100% CO	100% rCO
Origin		Cameroon	Recover
Commercial staple; UQL(w)	mm	29.6	19.1
5% – fiber length (n)	mm	33.8	22.7
Mean fiber length L (n)	mm	19.3	10.0
Short fiber content <12.7 mm (n)	%	25.9	70.9
Fiber Neps	1/g	243	2077
Seed Coat Neps	1/g	23	185

Fig. 29: Raw material properties of the commercial trial

Comercial trials

The trial set-up at Polopiqué was comparable to the laboratory trial. The customer is using 20% recycled fibers with 80% virgin cotton for yarn counts of up to Ne 30. This was used as the carded reference sample. This sample was compared to a 50/50 combed sample. A green recycled fiber from post-industrial origin provided by Recover was used for the trial (Fig. 29).

Fig. 30: The blend of virgin cotton and recycled fibers is processed on the comber at Portuguese customer Polopiqué.

The results at Polopiqué confirm the laboratory results. The yarn results can be improved significantly with the combed process, while maintaining a clearly higher share of green recycled fibers in the blend (Fig. 31 and 32).

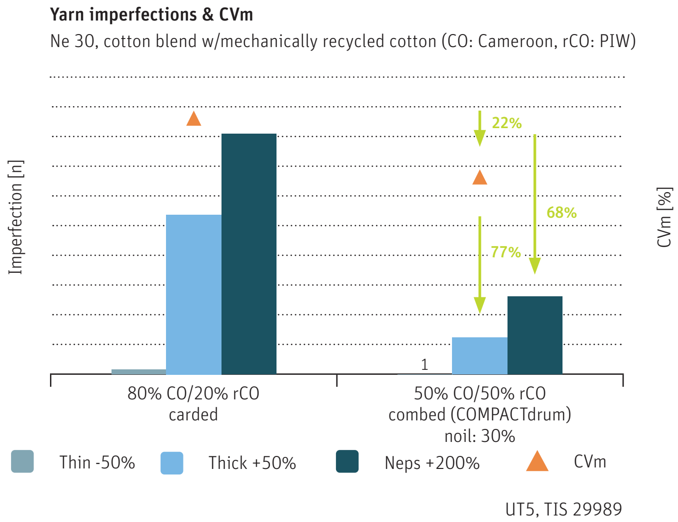


Fig. 31: The yarn manufactured with the combed process has a better quality although the share of recycled fibers is significantly higher.

Pique ring yarn, carded Ne 30/2
80% CO/20% rCO

Pique ring yarn, combed Ne 30/2
50% CO/50% rCO

Fig. 32: Also in the trial in the customer spinning mill, the fabric produced with the combed process is darker.

The improved yarn quality is also reflected in better pilling resistance of the fabric. The results are significantly better than in the 80/20 carded sample (Fig. 33). This means that while the recycled ratio is around twice as high in the combed fabric, the pilling resistance is also clearly higher, leading to a higher fabric quality and a longer lifetime of the garments.

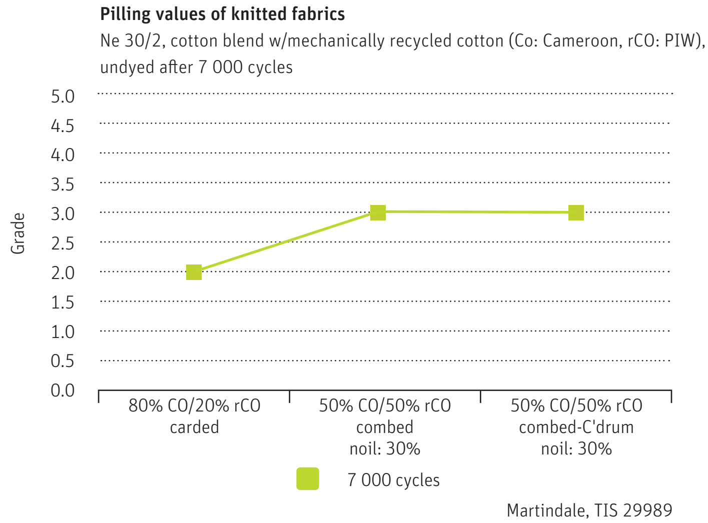


Fig. 33: The pilling resistance of the fabric is improved with the combed process.

Polopiqué – as a vertically integrated textile company – produced polo shirts from the combed recycled ring yarns from the trial (Fig. 34). The quality of these shirts underlines the results described above.

The quality of the garment is comparable to a virgin product and the use of Pique as a knitting pattern is creating a fabric structure that is perfect for using recycled ring yarns.

Fig. 34: The high quality of the polo shirt produced from the combed recycled ring yarn proves its practical suitability.

8. Finding the Right Application for the Noil

The big "disadvantage" of combing a recycled cotton blend is obviously the high amount of noil that is generated. One could argue that this is also contradicting the fiber-to-fiber recycling principle as a lot of fibers are removed on the comber. However, chapter 6.3 has shown that the combed yarns and fabrics still contain a high share of recycled fibers. And what about the composition of the noil? The recycled content of the noil for the tested 50/50 samples is estimated at around 75% while 25% are short fibers from the virgin cotton. The raw material properties of the comber noil are shown in Fig. 35.

So why not using this noil to produce recycled rotor yarns?

To investigate this question, the noil from the industrial trial with Polopiqué was brought from Portugal to the rotor spinning-customer Ferre in Spain. This company has a huge experience in rotor spinning of recycled fibers.

Three different blends were tried, always with the focus of keeping the share of the noil as high as possible. The yarn counts produced were Ne 12 and 16 (Fig. 36).

Raw material		**Comber noil**
Commercial staple; UQL (w)	mm	13.0
5% - fiber length (n)	mm	16.3
Mean fiber length L (n)	mm	7.9
Short-fiber content < 12.7 mm (n)	%	87.3
Fiber neps	1/g	277.0
Seed coat neps	1/g	13.0

Comber noil from Polopiqué's commercial trial

Fig. 35: Raw material properties of the noil for rotor spinning

Parameters	**100% combed noil yarn**	**Combed noil yarn – blend 1**	**Combed noil yarn – blend 2**
Process	Carded – rotor	Carded – rotor	Carded – rotor
Blend	Blowroom	Blowroom	Blowroom
Raw Mat. 1	100% Combing noil	80% Combing noil	80% Combing noil
Raw Mat. 2	–	20% Cotton	–
Raw Mat. 3	–	–	20% rPET
Yarn count (Ne)	12	12	16
Estimated recycling ratio (%)	75%	60%	80%*

Fig. 36: Properties of the noil samples and process parameters.

** Recycling ratio content: 60% rCO + 20% rPET*

As can be seen in the yarn results (unevenness and imperfections), the rotor spinning technology copes well with a high share of short fibers and recycled fibers. All results are comparable to rotor yarns from virgin material (Fig. 37).

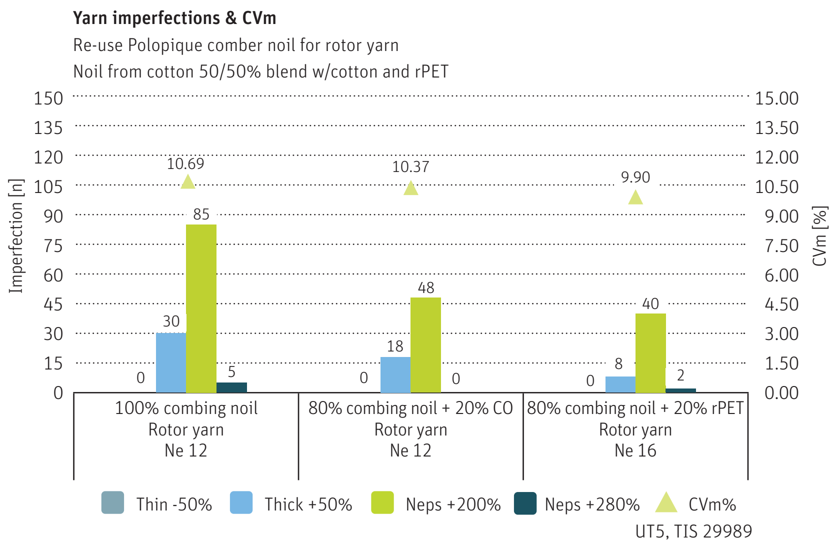


Fig. 37: The rotor spinning technology is well suited for the processing of short fibers and all noil samples are of good quality.

But the high SFC is manifesting itself in a low tenacity (Fig. 38). While the achieved tenacity could be enough for some applications, higher tenacity will be needed for most of the normal yarn applications. This means that either the yarn count has to become coarser or that the blend ratio of the noil must be reduced, e.g. to 60% noil / 40% rPET.

Overall, the trial has proven that the noil can be turned into rotor yarns, solving the problem of the higher noil level when combing recycled cotton blends. This also confirms that most of the recycled fibers that are brought into the process can be spun into new yarns, either as combed ring yarns or, if they are too short, as rotor yarns.

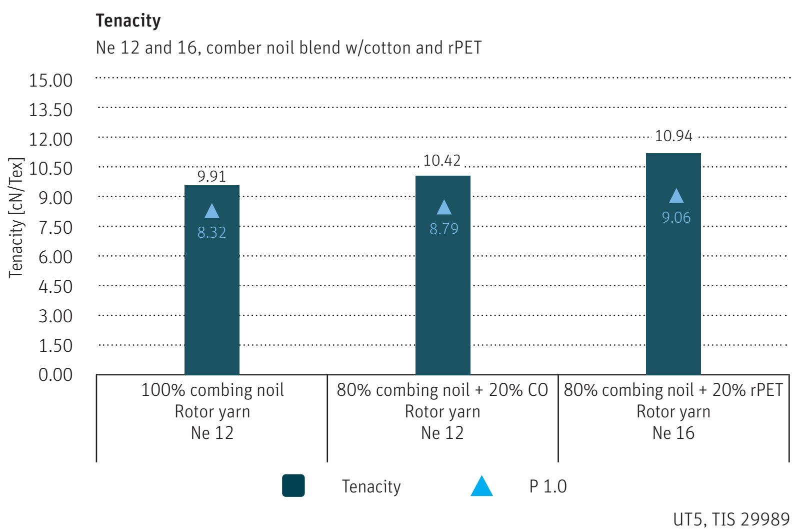


Fig. 38: The yarn tenacity of the noil samples is not sufficient for many applications, which indicates that the blend ratio has to be adapted.

9. Economic Viability

As the technological trials have proven that the combed process is an option to increase both yarn quality and recycled blend ratio of recycled cotton ring yarns, it is now important to assess the economic viability.

The combed process for recycled cotton blends is not yet established in the market and, as a result, the assessment of the economic viability must be based on some assumptions:

- The mill capacity was calculated for each example with around 836 kg/h ring spinning production volume. The combined process (50% CO/50% rCO combed ring and 60% noil/40% rPET rotor) was calculated with an additional 472 kg/h rotor spinning production volume.
- For this calculation, the cost of recycled fibers was estimated at 85% of the cost of virgin cotton.

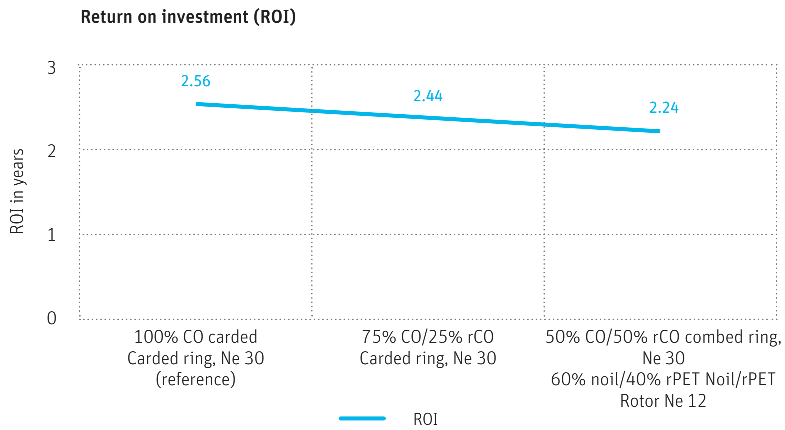


Fig. 39: The combined process offers an attractive ROI – the existing noil is processed to rotor yarn.

- The yarn price of 50% CO/50% rCO combed yarn is assumed to be the same as 100% CO combed or plus 10% compared to 100% CO carded.
- The yarn price of 75% CO/25% rCO carded yarn is plus 5% compared to 100% CO carded.
- Waste is estimated to be resold at 30% of the raw material price.
- Concerning the noil reuse in rotor yarn: rather than opting for resale, an alternative is to spin the noil into rotor yarns. The yarn price is considering standard prices for recycled rotor yarns.

Key financial figures compared to reference 100 CO carded ring spinning process

	75% CO/25% rCO carded	50% CO/50% rCO combed and 60% noil/40% rPET rotor
Raw material cost per kg	-4%	-13%
Hourly raw material consumption	+2%	+65%
Hourly yarn production	0%	+56%
Hourly conversion costs	+13%	+52%
Total capital investment	+12%	+61%
Annual profit	+17%	+84%

Fig. 40: The higher yarn production and lower raw material cost make the combined process profitable despite the higher capital investment.

Three different process set-ups are compared:

- 100% CO carded ring, Ne 30
- 75% CO/25% rCO carded ring, Ne 30
- Combined process: 50% CO/50% rCO combed ring, Ne 30 and 60% noil/40% rPET rotor, Ne 12

The stand-alone 50% CO/50% rCO combed ring process incurs in higher machine investment and results in the highest waste/noil level among the compared processes. However, this challenge can be addressed by generating revenue through the resale of waste and noil or, even more effectively, by producing recycled rotor yarns from the noil.

The combined process (50% CO/50% rCO combed ring and 60% noil/40% rPET rotor) offers an attractive return on investment (ROI) of 2.24 years (Fig. 39) with additional investment in a rotor spinning line (total investment increases by +61% compared to the reference). Spinning mills will face only a little additional raw material purchase of rPET. This subsequently leads to an annual profit increase of +84% compared to the reference (Fig. 40).

The combined process optimally utilizes recycled cotton fibers, with a proportion of 77% equivalent to the 75% CO/25% rCO carded ring process. This results in a significantly higher proportion of recycled fibers in the yarn, averaging at 40% in ring and rotor (roughly 80% in rotor yarn considering rPET) while consistently achieving high yarn quality standards in the ring spinning process.

With the ability to flexibly switch between 100% CO combed and 50% CO/50% rCO based on cost and revenue changes, this process offers an attractive option for environmentally conscious spinners.

10. Conclusion and Outlook

As the market is further exploring ways to increase the use of mechanically recycled fibers, this study offers a solution to increase both the recycling ratio and the yarn quality of ring yarns. This improvement allows an extension of the application range and can overall increase the market share of fiber-to-fiber recycling and closed-loop production in the short-staple spinning industry.

It underlines the need to pay more attention to the high number of neps in mechanically recycled material. This study tries to emphasize this point, as it can be seen from the results that the neps, together with the SFC, are the defining quality parameters of ring yarns. This finding should encourage more research and improvements into possible reductions of the neps in mechanically recycled fibers in the future. To further support the industry, the Rieter Recycled Fiber Classification was extended by the category “nep count”.

This study could successfully show that the combed process can significantly help to improve the ring yarn quality while achieving a much higher recycling ratio. It also shows ways how to successfully use the resulting noil for recycled rotor yarns.

Let’s have another look at the four questions, raised in the beginning:

Performance of recycled cotton blend in the combed ring spinning process

The trials in the laboratory as well as at customer Polopiqué confirm the good performance of recycled cotton blends on the comber, but also in the subsequent process steps. Due to the optimal winding process on the combing preparation system OMEGAlap, the unwinding of the laps on the comber was comparable to virgin cotton. The comber E 90 delivers best yarn quality at the lowest possible noil level and is therefore a very suitable comber for this application.

Impact of the combing process on the blending ratio

Three different methods were tested. Especially the color measurement and the calculation based on the noil level came to similar results. While more recycled fibers are eliminated into the noil than virgin cotton fibers, most of the recycled fibers remain in the combed blend. The results show that the recycling ratio changes from 50/50 to 60% virgin cotton/40% recycled cotton after the combing.

Impact of the combed process on yarn quality

All combed samples show an improved yarn quality at 60/40 compared to a carded 75/25 reference. Some of the values can even reach the 100% virgin cotton reference. Especially the number of imperfections and the unevenness of the yarns is significantly improved. The more noil is extracted the better the yarn quality can become (or the better the spinner can react to raw material variation).

Using combed recycled blends instead of carded recycled blends in the ring spinning process means reduced fiber fly and yarn breaks, as well as better performance on knitting and weaving machines and better fabric quality (less pilling and better washing stability).

Process costs of the combed process

The process costs show that due to the high waste and additional process steps, combed recycled cotton yarns are more costly to produce than carded yarns. The conversion costs are around 50% higher compared to the carded reference yarn. This shows that spinners need to get higher prices from the market to make the process profitable. With the clear benefit of better yarn quality at a higher recycling ratio, this should not be a problem, at least as long as there is no other process that can deliver the same benefits at a lower cost.

The rotor trials showed that the noil can be fully processed into good rotor yarns. Turning this “waste” into sellable, recycled yarn is key to making the process highly economical.

While the study could successfully show the benefits of combing recycled cotton blends, more work needs to be done in the future. An important topic is to get a GRS certification for this process and define how the labeling of the yarns can be done. Especially the determination of the resulting blend ratio in the yarn needs to be solved. Rieter will continue to work with the project partners on establishing fundamental rules for different blend ratios. While color measurement will help to establish these rules, tracers must be further developed to enable the determination of the blend ratio in a final product in an easy and practicable way.

Finally, this study is proof that good research can only be done cooperatively and therefore it would not have been possible without great project partners. Thanks to Recover, Polopiqué, Ferre, University of Leeds, Saxion University, and Tailorlux for their big support.

11. Notes

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