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Rieter Recycling Toolbox

Contents

1. Introduction

1.1. Situation

Although interest in fiber-to-fiber recycling in the textile industry remains strong and regulations such as the EU's Ecodesign of Sustainable Products (ESPR) and the Digital Product Passport (DPP) are approaching implementation, the adoption of mechanically recycled fibers has not met expectations from a few years ago. On the one hand, scaling the chemical recycling process has proven more difficult than originally thought. On the other hand, mechanically recycled fibers are available, but their effects on productivity, efficiency and quality in spinning and downstream processes have not always met market requirements.

Rieter continuously investigates and validates processes and techniques to enhance the processability of mechanically recycled fibers, with a focus on achieving stable processing performance and yarn quality close to that of virgin fibers.

An earlier Rieter research publication demonstrated that combing recycled fiber blends can effectively double the recycled fiber share (up to 40%) in ring spinning, while another study revealed that substituting man-made cellulosic fibers (MMCFs) for virgin cotton can further increase the share to 50%.

While improving yarn quality and productivity are primary focuses, practical integration of these processes into the textile value chain is decisive for scalable progress in recycling. This article demonstrates how the Rieter Recycling Toolbox, a combination of processing techniques, can be used by spinners and recyclers to move further toward overcoming these challenges.

1.2. Mechanical recycling: fiber quality

Over the years, the quality of mechanically recycled fibers has improved noticeably through incremental advancements in the cutting, opening and tearing processes on the recycler's end. As the pictures show, these improvements have mainly been achieved by increasing the opening degree of the fibers.

While the openness of the fibers could be improved, the basic limitations of mechanically recycled fibers continue to affect productivity, efficiency and quality in the spinning and downstream processes. Using mechanically recycled fibers can have a triple impact for spinners:

- higher process waste, mainly due to unopened yarn pieces and dust,
- lower production speed and efficiency throughout the manufacturing process, mainly due to a high short fiber content and
- reduced yarn and fabric quality, mainly due to a high number of neps and short fibers.

All of the above factors significantly increase the spinner's conversion costs.
To increase the industry's use of mechanically recycled fibers, the priority must be to reduce the negative impacts currently associated with them. This highlights the need for research into processes and techniques that improve recycled fiber quality and spinning performance.

Post-consumer denim 2020

Post-consumer denim 2023

1.3. The Rieter recycling toolbox

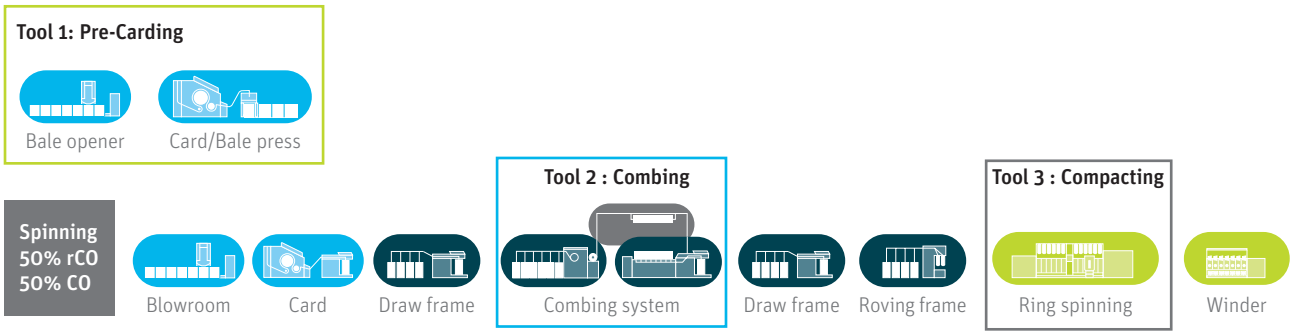
The research question was how mechanically recycled fibers can be blended and spun into yarn so that productivity during the ring spinning process and the resulting yarn quality match those of a virgin carded cotton yarn. As explained above, the main challenges with mechanically recycled fibers are unopened yarn and fabric segments, high short-fiber content and high nep content.

Over the course of several projects, three process steps were identified as vital to improving productivity and quality because they directly address the limitations of the recycled fibers:

Pre-Carding – an additional carding step performed only on recycled fibers to remove unopened yarn and fabric pieces and reduce the number of neps

Combing – to reduce the number of short fibers in the process

Compacting – to increase fiber incorporation into the yarn body and therefore increase tenacity as well as reduce hairiness and abrasion in downstream processes.



The recycling toolbox targets on achieving comparable performance to a virgin carded cotton in the following aspects:

- yarn quality – unevenness, imperfections, tensile strength, hairiness and abrasion,
- processing performance – production efficiency in spinning and downstream and
- fabric quality – appearance and lifetime of end applications.

Beyond quality and performance, the project also addresses the benefits for recyclers and spinners in efficient raw material utilization by minimizing waste and enabling its recycling at their respective stages, thereby enhancing circularity within the textile value chain.

2. Trial Set-Up

2.1. Raw material

Raw material		**CO** **Virgin cotton**	**rCO** **Recycled cotton**	**PrCO** **Pre-carded recycled cotton**
Origin		Senegal	Recover	
Type		Virgin cotton	Post-Industrial Waste - White	
Commercial staple; UQL(w)	mm	29.8	17.1	23.9
5% fiber length (n)	mm	34.1	20.7	28.3
Mean fiber length L (n)	mm	20.2	8.8	13.2
Short fiber content < 12.7 mm (n)	%	22.1	77.9	53.3
Fiber neps	1/g	184.0	1007.0	923.0
Seed coat neps	1/g	24.0	50.0	5.0

2.2. Experimental plan

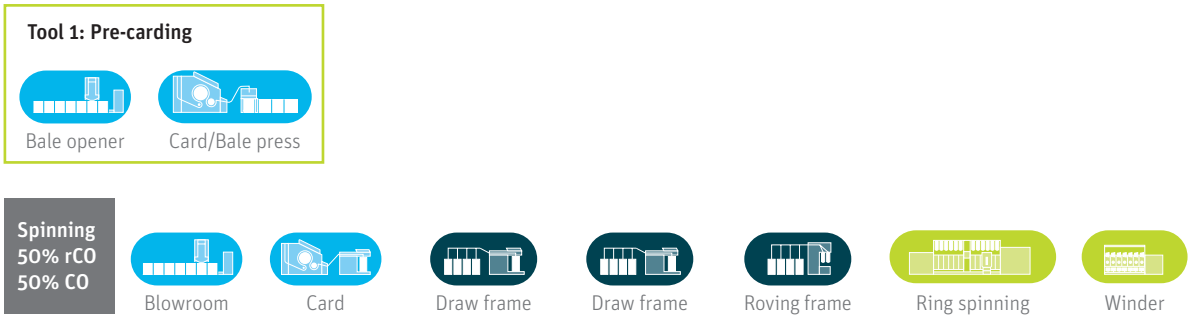
CO **Virgin cotton**	100%	50%	50%	50%	50%	50%
rCO Recycled cotton		50%		50%		
PrCO Pre-carded recycled cotton			50%		50%	50%
Trial positions	100% Virgin cotton	50% Virgin cotton 50% Recycled cotton	50% Virgin cotton 50% Pre-carded recycled cotton	50% Virgin cotton 50% Recycled cotton combed	50% Virgin cotton 50% Pre-carded recycled cotton combed	50% Virgin cotton 50% Pre-carded recycled cotton combed compact

Ring spinning – 100 % Cotton carded

Ring and Compact spinning – 100 % Cotton combed

3. Results and Discussion

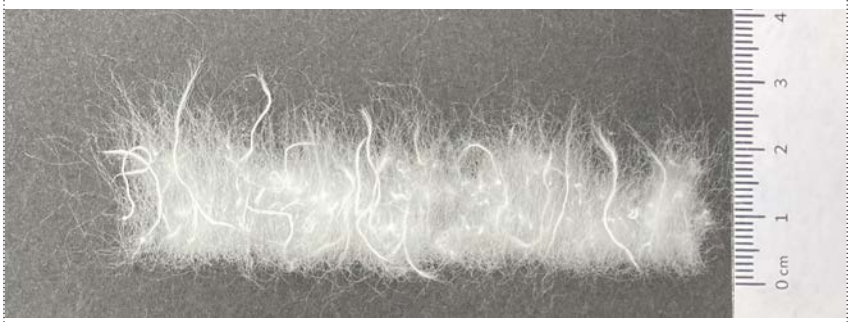
3.1. Recycling toolbox: impact of pre-carding



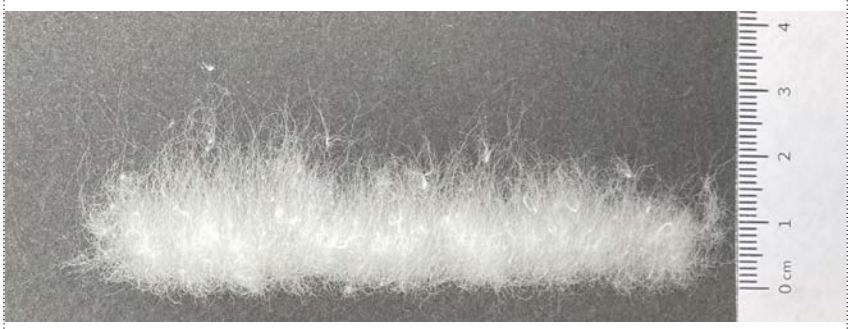
Pre-carding is considered as an additional fiber refinement step used exclusively with recycled fibers. The goal of this process is to thoroughly remove all unopened yarn pieces, significantly reduce the number of neps, and eliminate dust. Instead of producing a sliver, the recycled fibers are either fed back into a bale press or can be blended directly in the blowroom. The effect of this cleaning step on the spinning process is shown on the next pages.

Waste reduction: Using recycled fibers increases waste levels in the blowroom and during carding. This increase in waste occurs because many unopened yarn pieces are removed, typically at the licker-in stage of the card. These yarn pieces tend to be quite heavy, resulting in waste levels that can increase by 50% to 100% compared to 100% virgin cotton. This situation also negatively affects the blending ratio, as more recycled fibers are discarded than virgin fibers. Using pre-carded recycled fibers normalizes waste levels by avoiding all the above mentioned problems.

Original recycled fibers



After pre-carding



Removal of neps: The mechanical recycling process generates numerous neps, which are small pieces of unopened yarn. If these neps are not removed, they will be visible in the yarn. The yarn imperfections indicate that applying the pre-carding process reduces the occurrence of thick places and neps by approximately 50% compared to standard recycled fibers. The improvement is even more significant for larger neps (+280% and +400%), which also decreases the number of yarn cuts on the winding machine. The overall effect is also clearly seen in the final fabric, with far fewer large, visible neps.

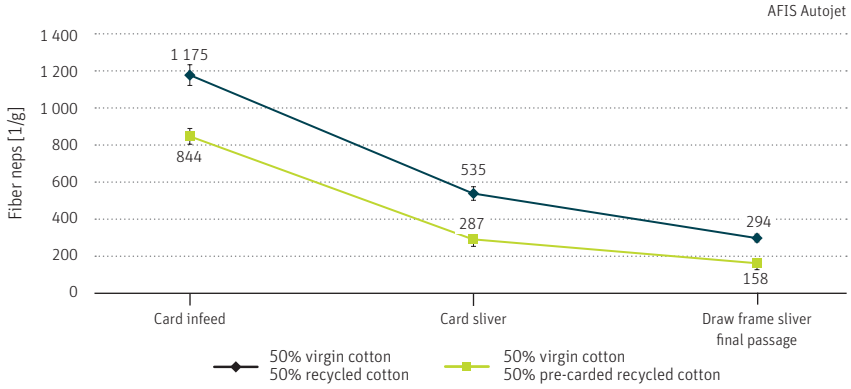
Removal of dust: Pre-Carding can help remove much of the remaining dust in recycled fibers. By removing additional dust during pre-carding, dust creation during the spinning process can be reduced, which will reduce cleaning efforts during the spinning process.

While the pre-carding process cleans the recycled fibers, certain other key parameters, such as short-fiber content, will remain unchanged. As a result, yarn characteristics like tenacity and hairiness will be comparable to those of the original recycled material. Since the short-fiber content does not change, productivity adjustments could still be necessary, such as reducing ring spindle speeds, when compared to spinning 100% virgin cotton yarns.

3.1.1. Fiber results

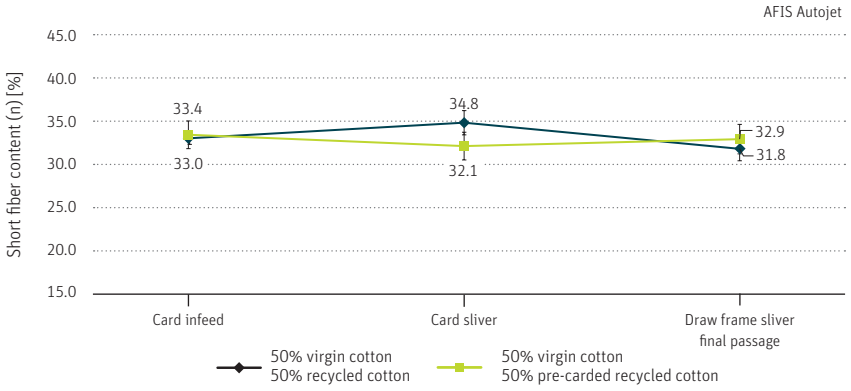
Impact of Pre-Carding

Fiber neps



Impact of Pre-Carding

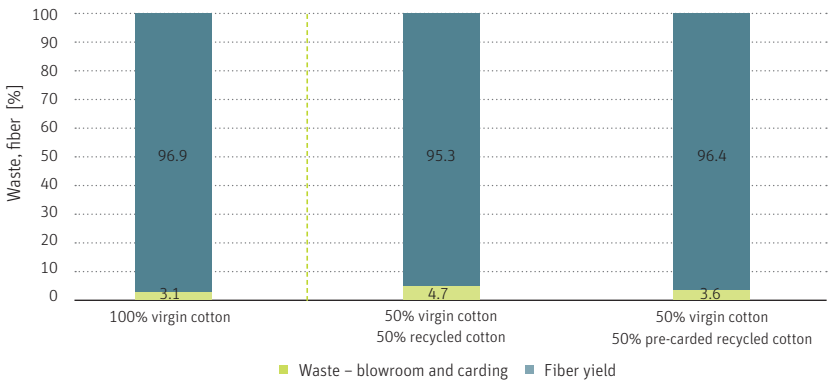
Short fiber content (n)



3.1.2. Process waste and fiber yield

Impact of Pre-Carding

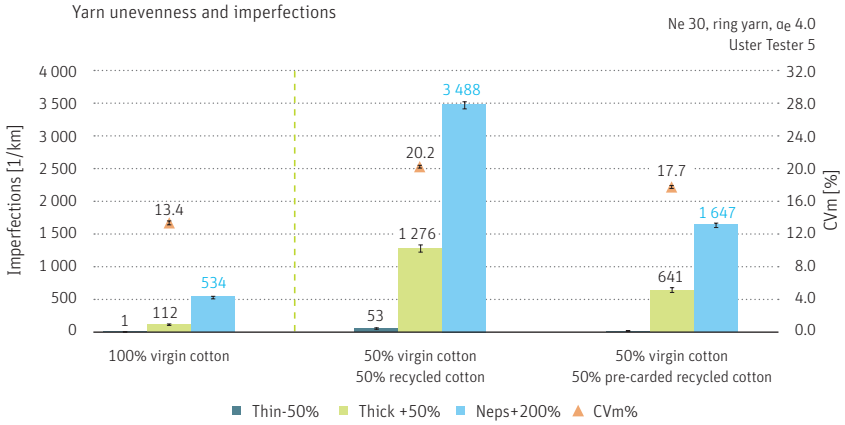
Process waste and fiber yield



3.1.3. Yarn results

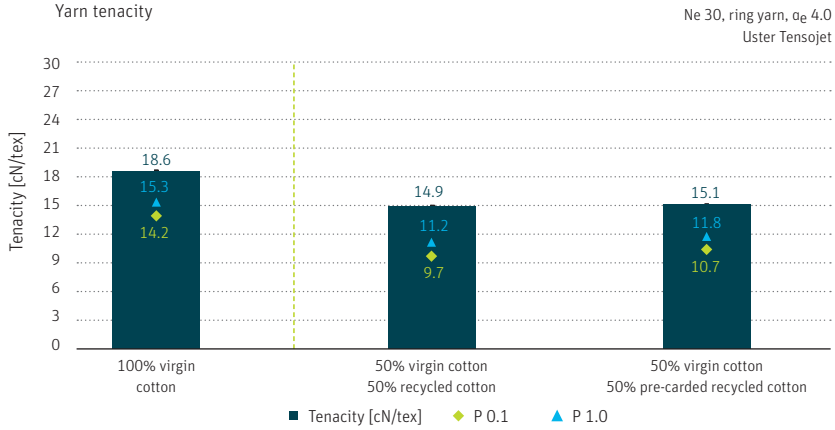
Impact of Pre-Carding

Yarn unevenness and imperfections



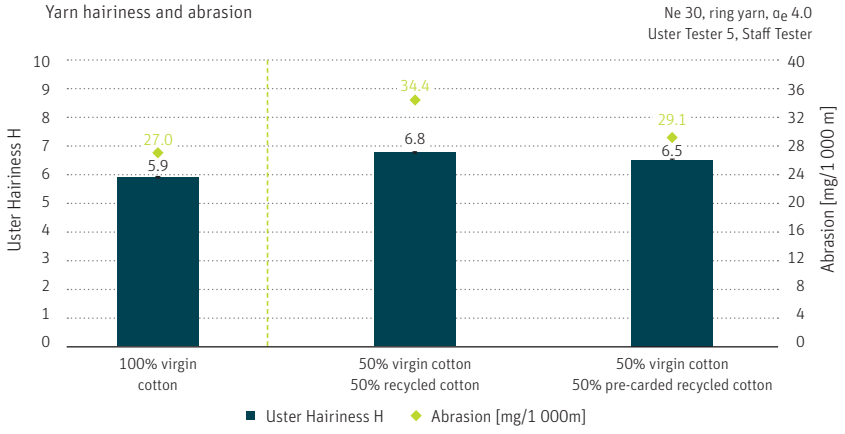
Impact of Pre-Carding

Yarn tenacity



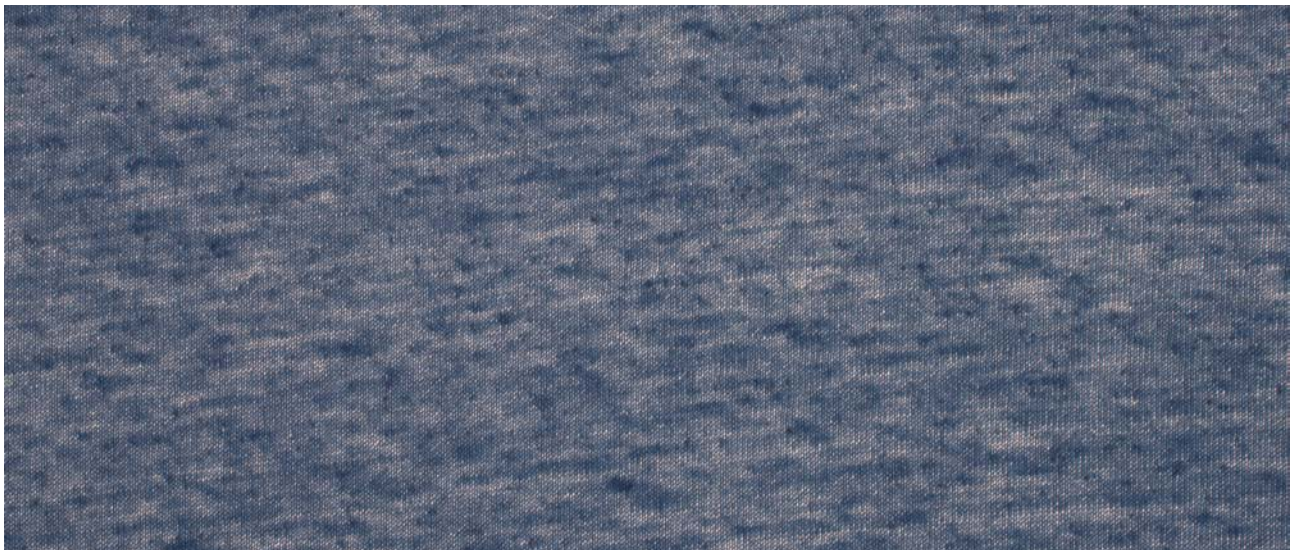
Impact of Pre-Carding

Yarn hairiness and abrasion

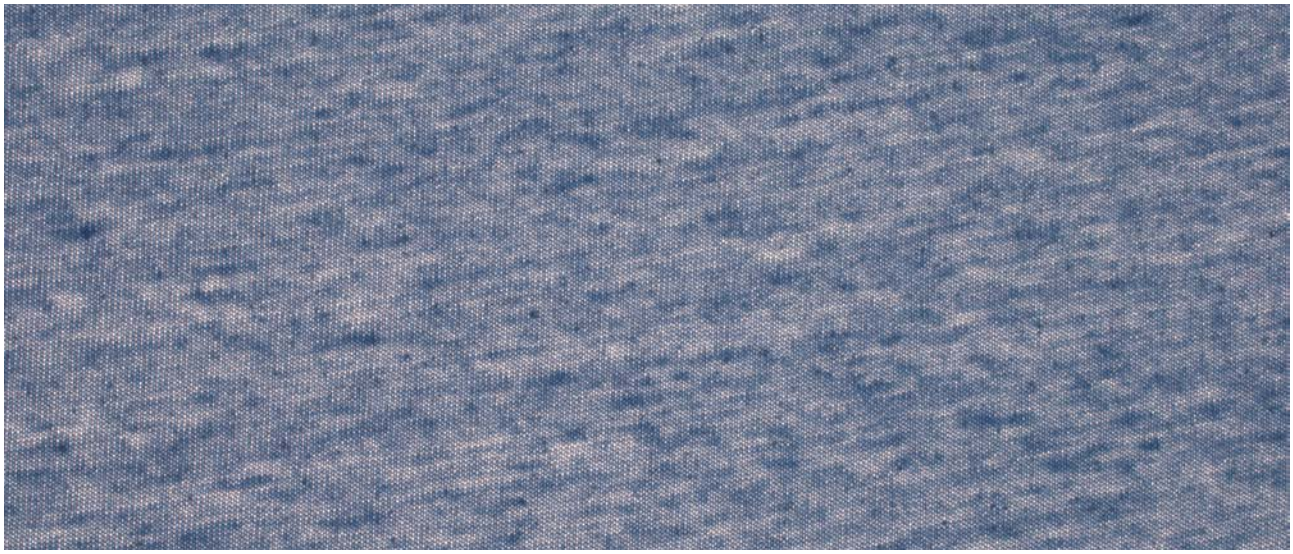


3.1.4. Knitted fabric quality

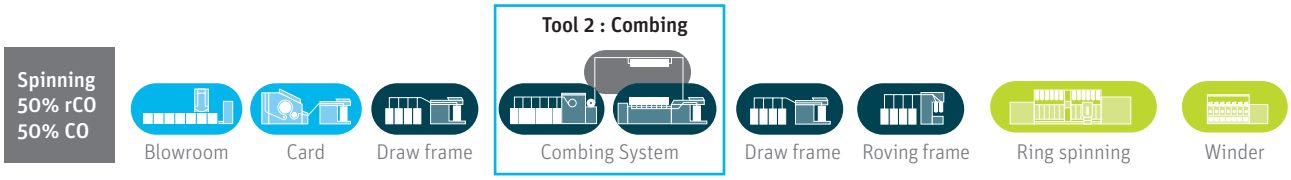
50% virgin cotton / 50% recycled cotton



50% virgin cotton / 50% pre-carded recycled cotton



3.2. Recycling toolbox: impact of combing



While the pre-carding process is designed to ensure the cleanliness of recycled fibers, the combing process focuses on reducing the short fiber content in the fiber blend. This reduction is crucial for improving the various drafting stages over the whole ring spinning process (from the draw frames to the ring spinning machine) as short fibers tend to group and move together, leading to a high unevenness and the creation of thick places. Additionally, the combing process enhances the yarn's tenacity and abrasion resistance.

Mechanically recycled fibers often contain a high percentage of short fibers. When blended with virgin cotton, the overall short fiber content (SFC(n)) can quickly exceed 30%, the maximum allowed for finer carded ring yarns, specifically those with a count of Ne 24 or finer.

Using the combing process significantly reduces the short fiber content in the blend, as shown in the charts below. This reduction alters the blending ratio since more short recycled fibers will be removed on the comber.

Based on prior research and considering a 20% noil rate for this project, it can be estimated that the blending ratio changes from 50% virgin cotton/50% recycled cotton to 60% virgin cotton/40% recycled cotton.

By applying the combing process, the downstream spinning process can be operated just like a virgin carded cotton process.

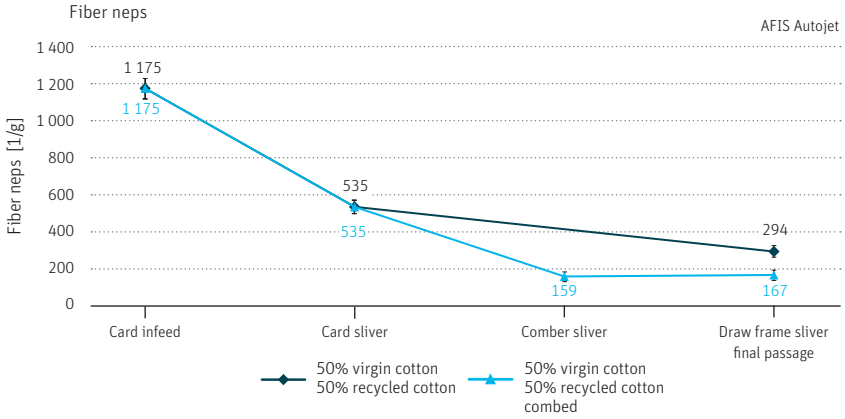
The benefits of using the combing process to enhance the spinning of recycled fiber blends, its influence on the blend ratio, and the potential use of noil have been explained and described in detail in the separate special print. "Enhancing Recycling Ring Yarn Quality," which can be accessed via the QR code shown below.

https://l.ead.me/bgt5ia

3.2.1. Fiber results

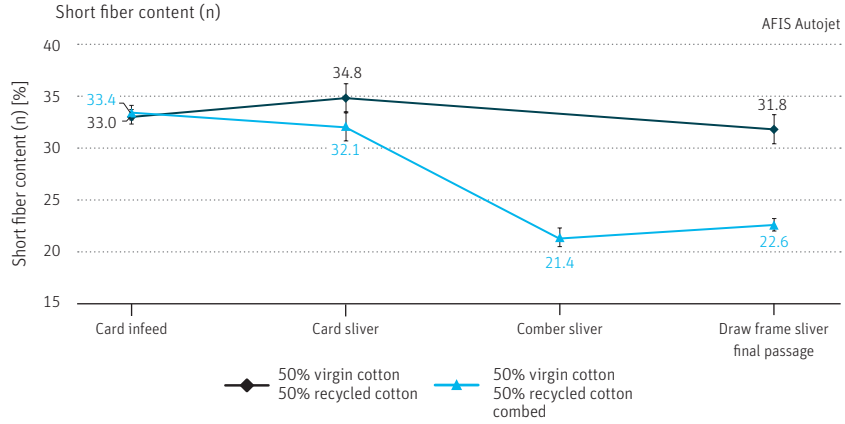
Impact of Combing

Fiber neps



Impact of Combing

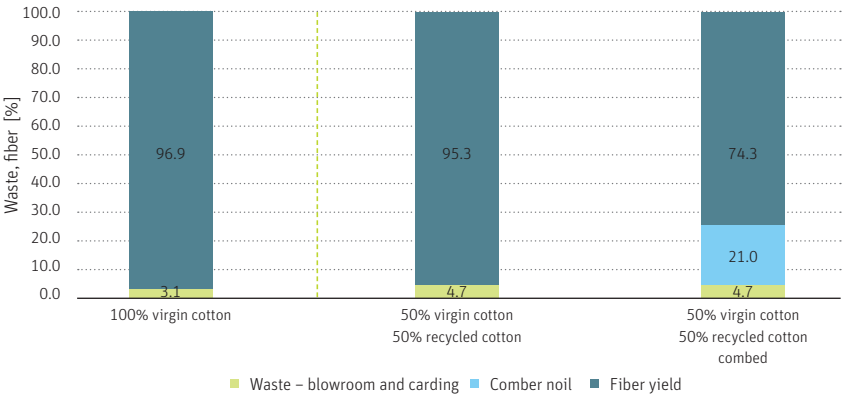
Short fiber content (n)



3.2.2. Process waste and fiber yield

Impact of Combing

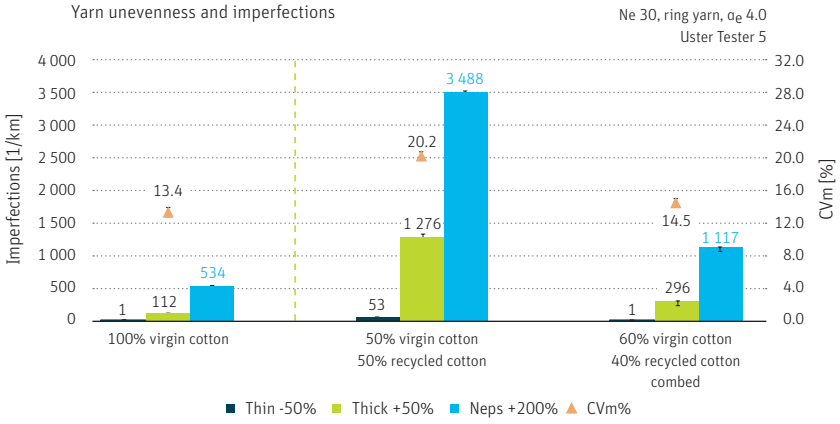
Process waste and fiber yield



3.2.3. Yarn results

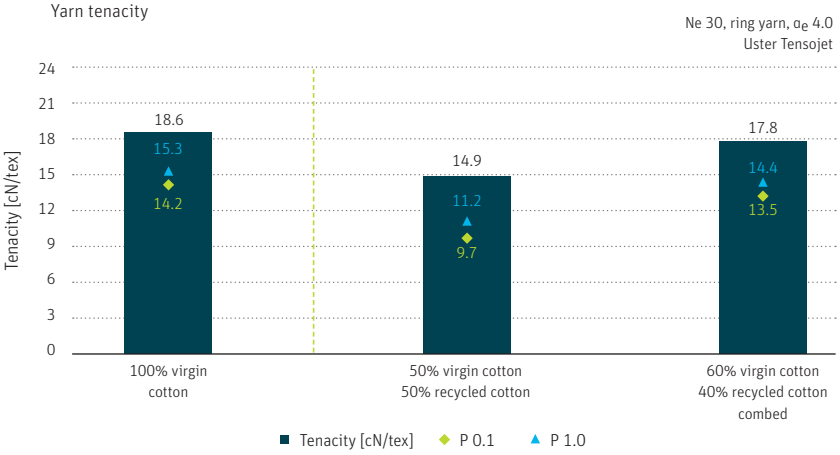
Impact of Combing

Yarn unevenness and imperfections



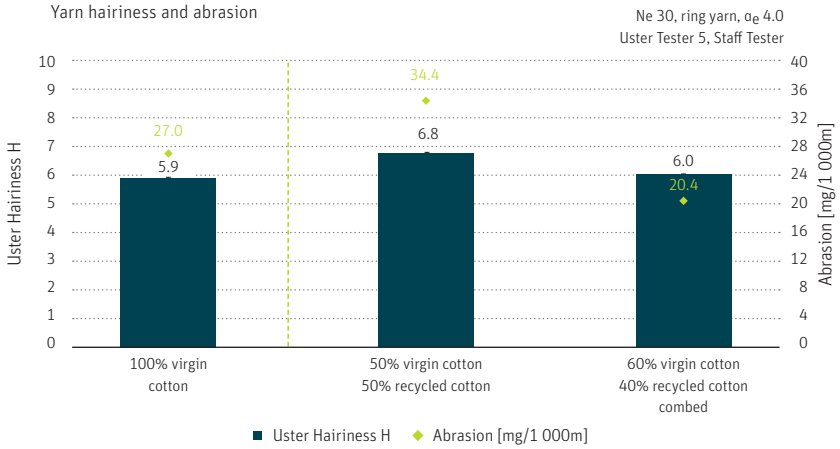
Impact of Combing

Yarn tenacity



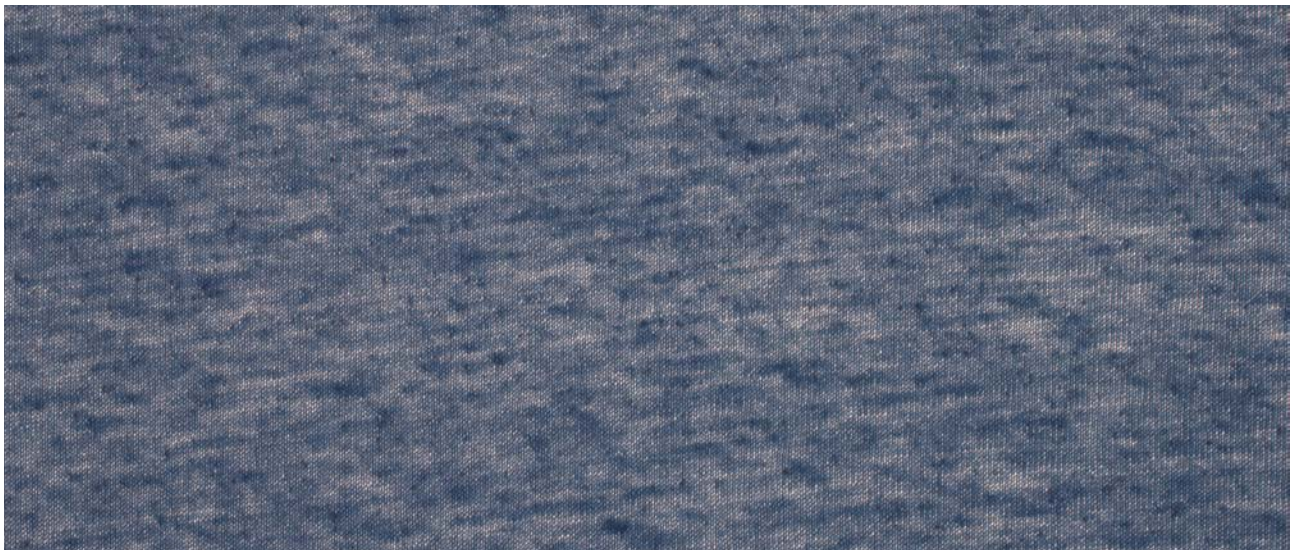
Impact of Combing

Yarn hairiness and abrasion



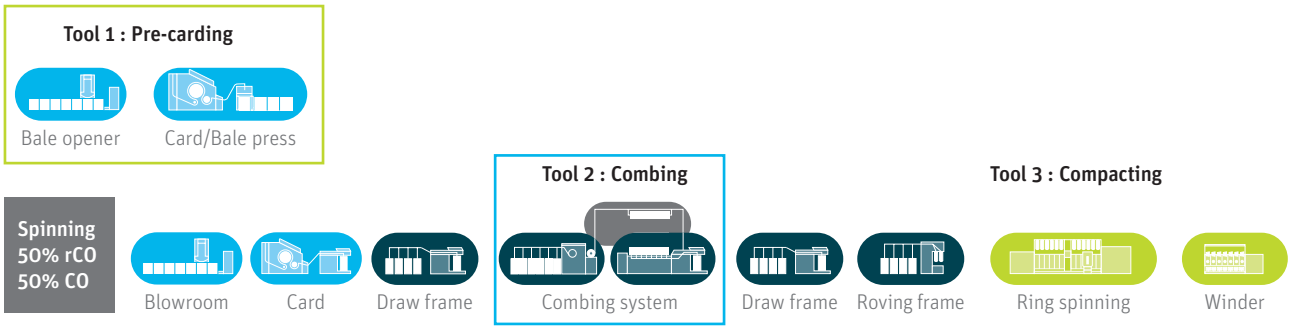
3.2.4. Knitted fabric quality

50% virgin cotton / 50% recycled cotton



50% virgin cotton / 50% recycled
cotton – combed

3.3. Recycling toolbox: impact of pre-carding and combing



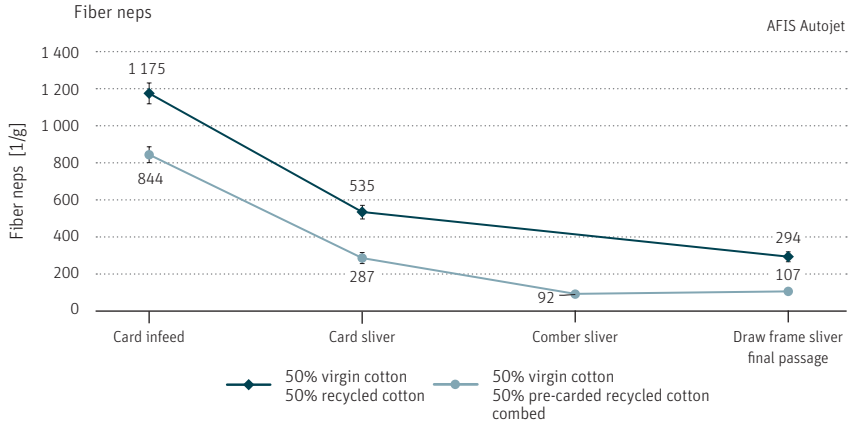
By combining pre-carding and combing, spinners can achieve yarn quality similar to that of virgin cotton, even when using up to 50% recycled fibers in the blend. Pre-carding effectively removes larger neps, while combing reduces the presence of short fibers. This combination enhances yarn uniformity, minimizes imperfections, and increases strength. It also allows the entire spinning line to operate as efficiently as a traditional spinning mill processing virgin fibers.

However, the strength of the yarn cannot fully reach the same level as that of 100% virgin cotton. The reason for this is that, although the blend has a comparable short fiber content after the combing process, it still lacks longer fibers since 40% of the fibers in the blend are derived from recycled sources.

3.3.1. Fiber results

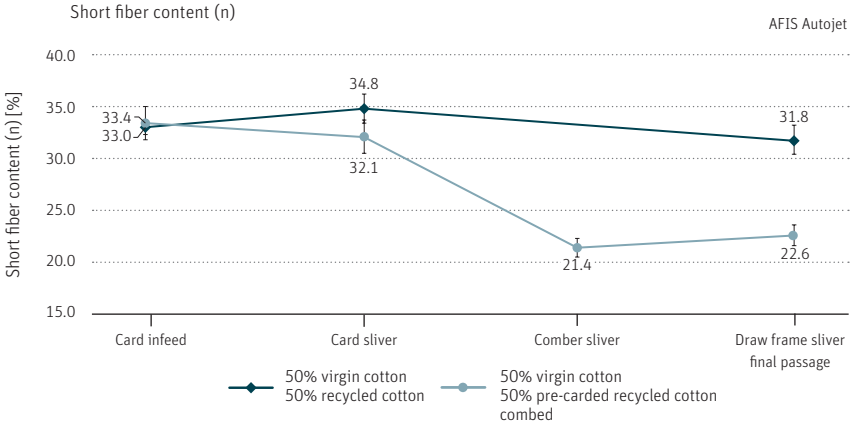
Impact of Pre-Carding and Combing

Fiber neps



Impact of Pre-Carding and Combing

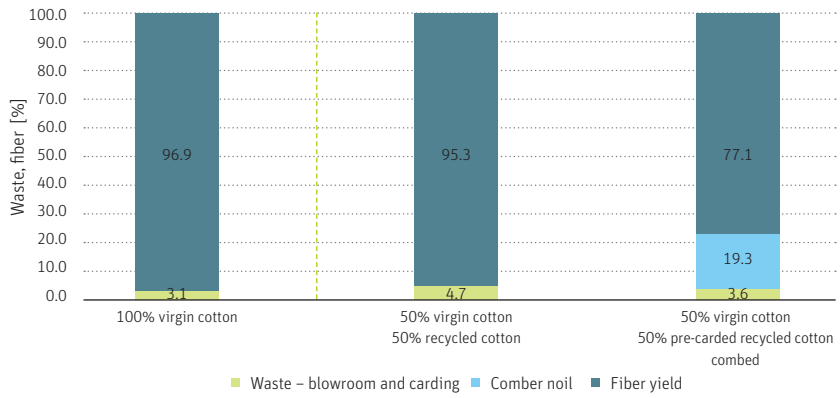
Short fiber content (n)



3.3.2. Process waste and fiber yield

Impact of Pre-Carding and Combing

Process waste and fiber yield

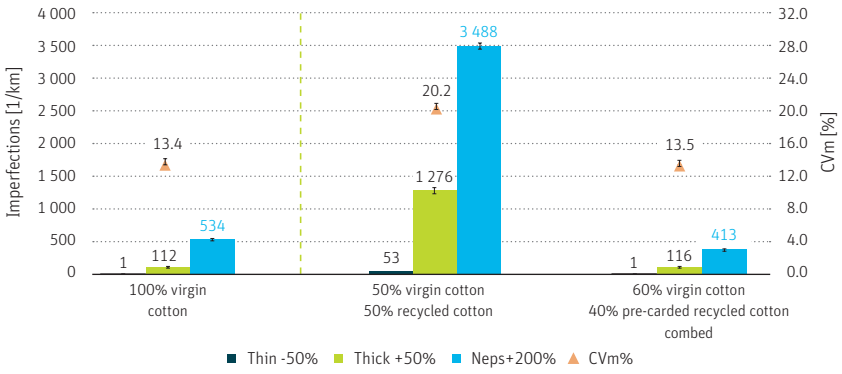


3.3.3. Yarn results

Impact of Pre-Carding and Combing

Yarn unevenness and imperfections

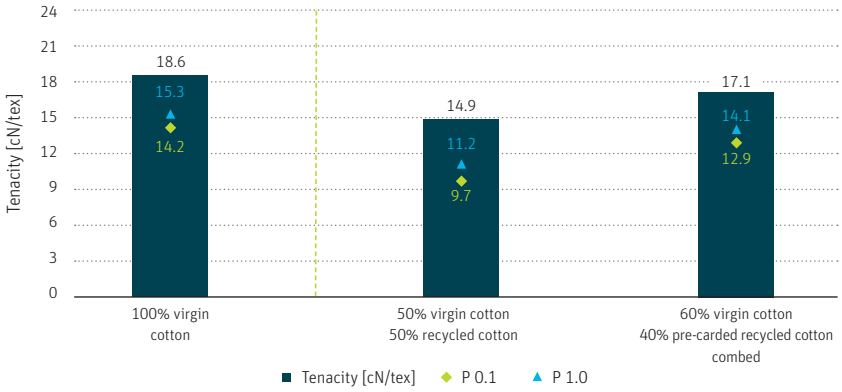
Ne 30, ring yarn, α_e 4.0
Uster Tester 5



Impact of Pre-Carding and Combing

Yarn tenacity

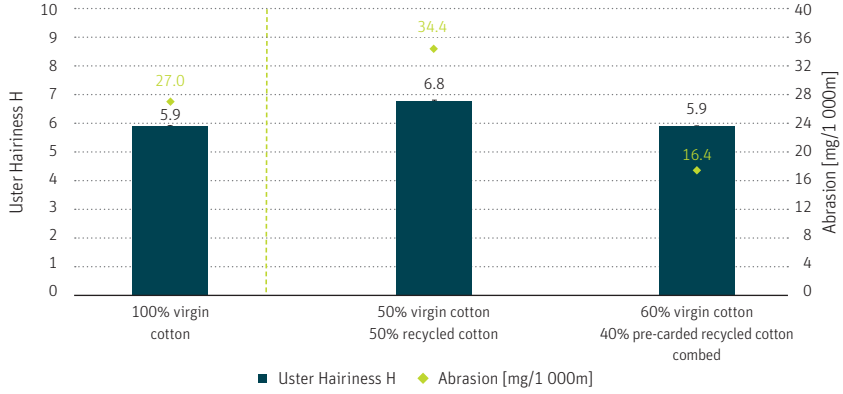
Ne 30, ring yarn, α_e 4.0
Uster Tensojet



Impact of Pre-Carding and Combing

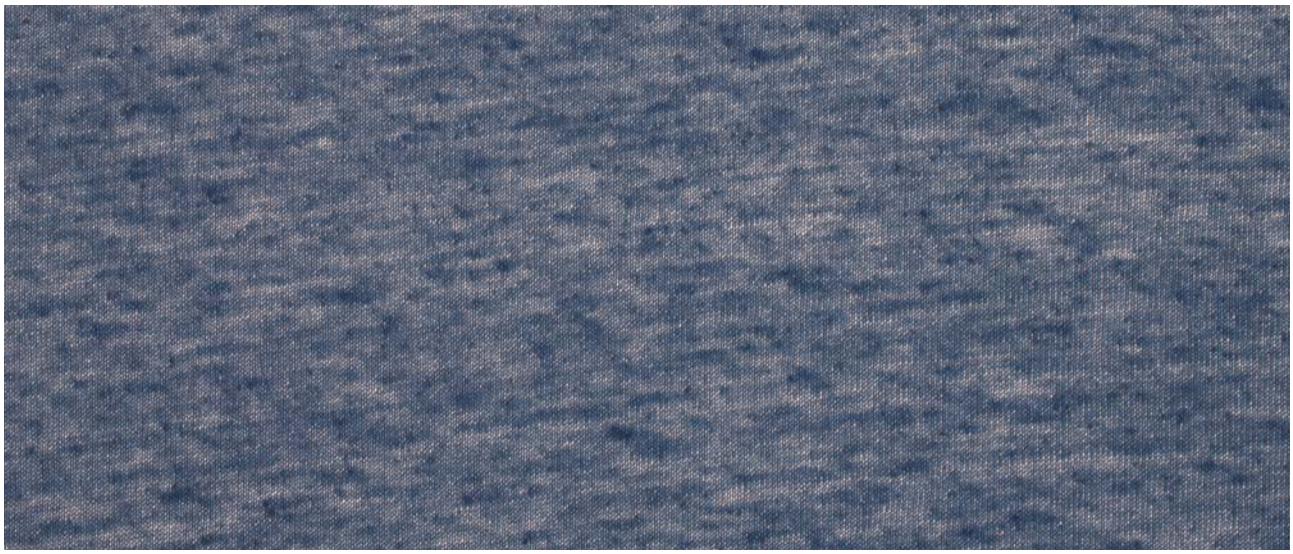
Yarn hairiness and abrasion

Ne 30, ring yarn, α_e 4.0
Uster Tester 5, Staff Tester



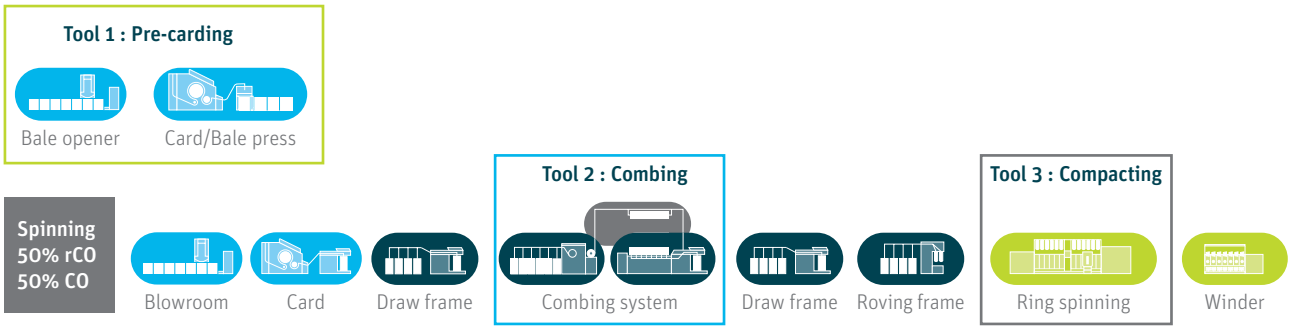
3.3.4. Knitted fabric quality

50% virgin cotton / 50% recycled cotton



50% virgin cotton / 50% pre-carded
recycled cotton - combed

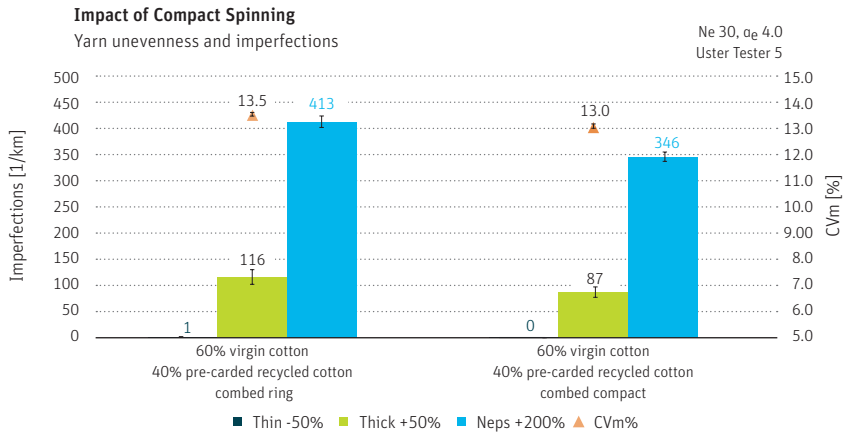
3.4. Recycling toolbox: impact of compact spinning

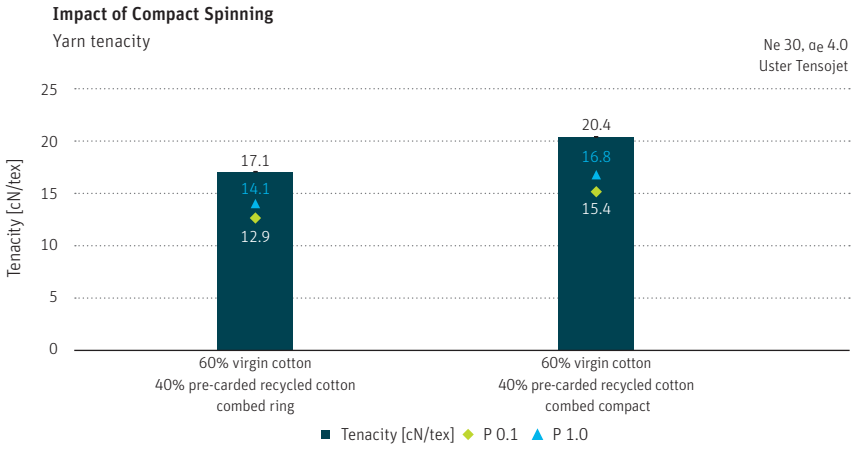


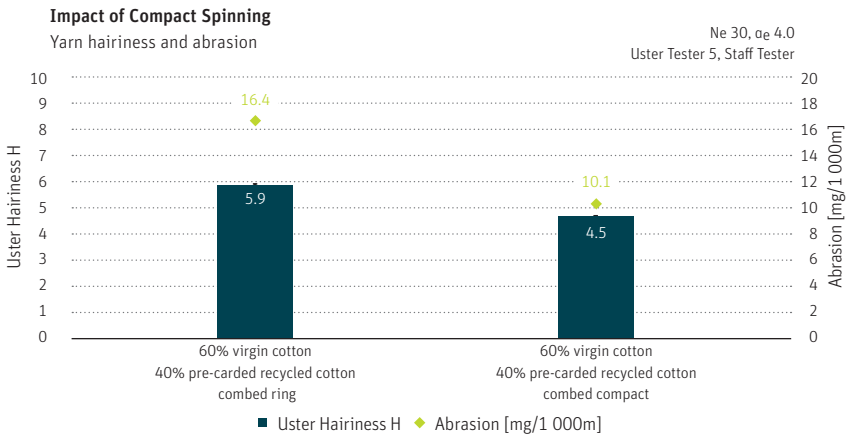
The first two tools have already reached productivity levels and yarn quality comparable to carded virgin cotton. However, they still lack in yarn strength. This is where compacting comes into play.

By using a compact-yarn spinning system, the integration of fibers into the yarn body is enhanced, resulting in increased yarn strength and improved abrasion resistance.

3.4.1. Yarn results







3.4.2. Knitted fabric quality

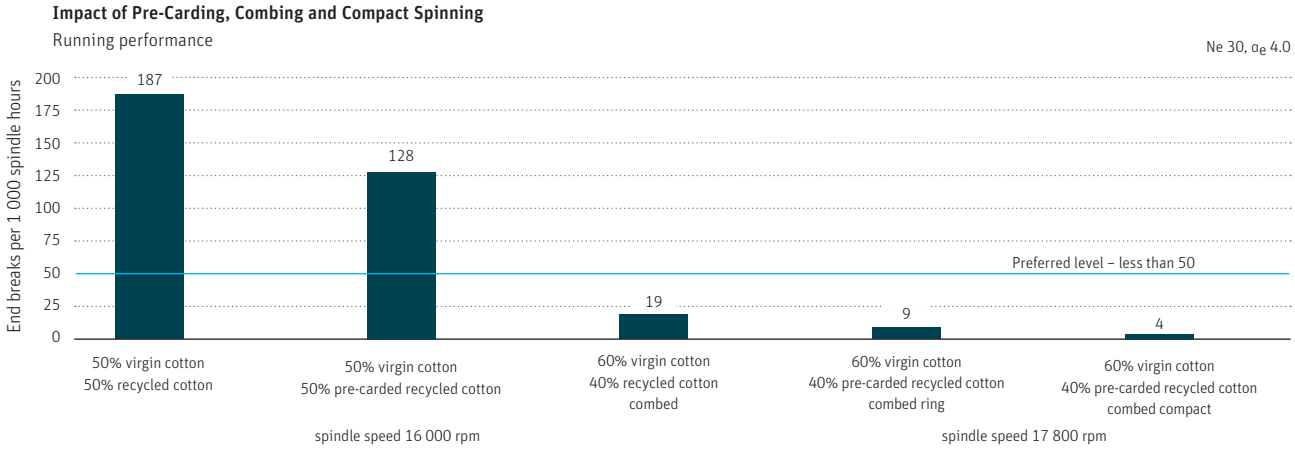
50% virgin cotton / 50% pre-carded
recycled cotton – combed ring

50% virgin cotton / 50% pre-carded
recycled cotton – combed compact

3.5. Running performance: impact of pre-carding, combing and compact spinning

The efficiency of spinning a recycled fiber blend into yarn also depends significantly on the number of end breaks experienced on the ring spinning machine. Acceptable end break levels can differ between regions, spinning mills and applications, but a common target today is to achieve fewer than 50 end breaks per 1 000 spindle hours of operation.

In this trial, the desired level could only be attained by utilizing the combing process, as indicated in the chart. Although pre-carding could reduce the number of end breaks by about one-third, the overall level still exceeded 100 end breaks per 1 000 spindle hours. This highlights the necessity for spinners to manage the short-fiber content in the blend effectively. In this case, this can be accomplished either by combing or by reducing the blend ratio of recycled fibers to under 50% (for example, to 25%).



4. Conclusion

4.1. Summary

This report explores three different tools or process steps that can help to increase the processability and quality of mechanically recycled fibers - blends and finally of the yarn.

Pre-carding is an additional carding step performed before the standard spinning process, specifically on recycled fibers to remove unopened yarn and fabric pieces and reduce the number of neps in the mechanically recycled fibers. By applying pre-carding in this trial, yarn imperfections were reduced by 50% (mainly thick places and neps), while waste levels during spinning could approach those of virgin cotton. By implementing this step, spinners can improve quality and spinnability while maintaining the blending ratio between recycled and virgin fibers throughout the process.

Combing is the right process to remove short fibers and further reduce neps. Controlling the short fiber content (SFC) in the blend is vital to achieve a good running performance and yarn quality. Without the combing process, the SFC threshold at which the ring spinning process becomes unstable can be reached very early, depending on the SFC of the recycled fibers and the virgin cotton. Thanks to the combing process, the share of recycled fiber can often be more than doubled, while also further improving the yarn quality.

In this trial, the combing process alone could reduce imperfections by roughly 65%, while a combination of pre-carding and combing could reduce them by more than 90% compared to the reference recycled sample. Combing also plays an important role in mitigating the loss of tenacity of recycled yarns. By applying this step, the yarn tenacity can reach the same level as that of a comparable yarn made from 100% virgin cotton. It is important to note, though, that the combing process changes the blending ratio between recycled and virgin fibers.

Compact Spinning, as the third tool, further helps to reduce yarn hairiness and abrasion, which are typically pronounced in recycled yarns, by better integration of the short fibers in the yarn structure. It also increases yarn strength, or it could be used to increase production by allowing a reduction in the twist multiplier. The compact yarn structure further enhances the fabric appearance and lifetime of the end application.

The three tools, whether used individually or in combination, allow ring spinners to spin mechanically recycled fiber blends with optimal productivity and quality.

4.2. Conclusion and outlook

Technological solutions exist

The results of this project demonstrate that the technological solutions for spinning blends with mechanically recycled fibers already exist. These technologies can be applied based on the quality of the raw materials and the intended applications. Many spinning mills already have the necessary machinery to implement all three processes. Therefore, the question is no longer whether mechanically recycled fibers can be spun into high-quality ring yarns, but rather how to develop an economically viable process for doing so.

Waste can be reused or sold

For spinners, the separated waste from pre-carding could be sold to non-woven manufactures, while the comber noil can be reused and spun into recycled rotor yarns.

Pre-carding and combing to be integrated in recycling process

Through discussions with all relevant stakeholders, it became evident that integrating pre-carding and combing into the recycling process, rather than the spinning process, would be the most feasible option. The advantages of this approach are significant. As recyclers continue to work on 100% recycled fibers and not blends, the extracted material that would typically be considered as waste in a spinning mill becomes valuable raw material for other industries. The process can be compared to a dairy operation, but instead of turning milk into cream or yogurt, recyclers can send their longer, clean fibers to ring spinners, while the shorter fibers can be sent to rotor spinners, non-woven manufacturers or chemical recyclers.

Recycling tools enhance processability and yarn quality

Combining pre-carding and combing is particularly beneficial for post-consumer recycling, where it is anticipated that the fibers may be shorter than those from post-industrial sources, that are available today. By utilizing the tools described, recyclers and spinners can enhance the processability and finally the yarn quality of mechanically recycled fibers. More importantly, these tools provide a solution to the current gap between textile recycling and spinning, supporting a more circular future of the textile production.

5. Appendix

5.1. Spin plan

5.1.1. Pre-carding process of recycled cotton – 100% rCO

Machine	Type	Infeed ktex/tex	Doublings	Draft	Output ktex/tex	Production speed m/min, rpm	Remarks
Opening & Cleaning	MBO – B3/4 → UNIstore A79						
Card	C 80				8	90 kg/h	Fleece – web suction to Bale press

5.1.2. Carded process – conventional ring

Machine	Type	Infeed ktex/tex	Doublings	Draft	Output ktex/tex	Production speed m/min, rpm	Remarks
Card	C 80		1	1	7.0		90 kg/h
SB draw frame	SB-D 50	7.0	4	4.7	6.0	500 m/min	
RSB draw frame	RSB-D 50	6.0	4	4.7	5.1	450 m/min	
Roving	F 39	5.1	1	6.9	740		
Ring spinning	G 35	740	1	37.8	19.6	16 000; αe 4.0	Ne 30 / Conventional

5.1.3. Combed process – conventional ring and COMPACTdrum

Machine	Type	Infeed ktex/tex	Doublings	Draft	Output ktex/tex	Production speed m/min, rpm	Remarks
Card	C 80		1	1	7.0		90 kg/h
SB draw frame	SB-D 50	7.0	3	4.2	5.0	600 m/min	
OMEGAlap	E 35	5.0	24	1.54	79.0	180 m/min	
Comber	E 80	79.0	8	14.27	6.0	480 m/min feed amount 5.2 mm	top comb +0.5 mm detach distance 7.5 mm nipper – circular comb-distance 0.3 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	1	37.8	19.6	16 000; αe 4.0	Ne 30, conventional ring
Ring spinning	G 35	740	1	37.8	19.6	17 800; αe 4.0	Ne 30, COMPACTdrum

6. Notes

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