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October 2025

Advancing Circularity: Blending Man-Made Cellulosic Fibers with Recycled Cotton

Contents

1. Introduction

Building on previous research into 100% cotton recycled yarns, this study explores blending mechanically recycled cotton with man-made cellulosic fibers (MMCF) to create 100% cellulosic yarns that maintain cotton characteristics. The research represents a collaboration between Rieter, Grasim Industries (Aditya Birla Group) – a global leader in viscose staple fibers – and Recover, a Spanish specialist in mechanical fiber recycling.

Birla – Excel (Lyocell) Fibers

The lyocell fibers "Birla Excel", developed by Grasim Industries, are advanced man-made cellulosic fibers (MMCFs) that combine sustainability with high performance. These third-generation MMCFs use wood pulp from sustainably managed forests and employ a closed-loop production process that recycles 99% of water and chemicals, minimizing environmental impact. The biodegradable fibers meet strict ecological standards while delivering key performance characteristics: soft texture, high moisture absorption, breathability, anti-bacterial properties, and high tensile strength. When blended with natural or synthetic fibers, Excel enhances the overall textile performance, feel, and appearance across apparel, home textiles, and non-woven applications.

Recover – Recycled Fibers

Recover transforms post-industrial, pre-consumer, and post-consumer textile waste into premium recycled cotton fibers and blends. The company integrates directly into supply chains through strategic partnerships to create closed-loop sustainable solutions. Their post-industrial textile waste (PIW) primarily comes from textile and garment manufacturing, consisting of cutting clips, selvedge waste, and fabric scraps. These materials undergo careful sorting before Recover processes them into high-quality fibers for spinning industry blends.

Investigation: Increase Recycled Content in Yarn

The study investigates how Excel fibers can increase recycled content in yarn blends while maintaining quality. Three Excel fiber variants were compared, differing in length and fineness, against a benchmark blend of 80% virgin cotton and 20% Recover recycled cotton. The research evaluates both spinning performance and final product characteristics in yarns and fabrics. By using Birla's Excel (lyocell) as an alternative to virgin cotton in blends with Recover's post-industrial waste (PIW) fibers, the aim was to identify optimal fiber specifications that maximize recycled content without compromising quality.

2. Research rationale

The goal of optimizing recycling ring spinning processes is to maximize recycled fiber content while achieving quality comparable to virgin materials. This presents two key challenges: first, ensuring recycled fiber quality (considering opening degree, fiber length, and nep count), and second, selecting appropriate virgin fibers for blending. Traditional blends using virgin cotton face limitations due to short-fiber content (SFC) and nep count issues, typically restricting recycled content to around 20%.

Man-made cellulosic fibers (MMCF) offer compelling advantages over virgin cotton, providing minimal short-fiber content (SFC) and neps, consistent fiber length, and maintaining 100% cellulosic composition. However, successful blending with short cotton fibers requires careful selection of fiber properties. Our study examined three Excel (Lyocell) fiber variants, differing in length (34 mm and 38 mm) and fineness (1.0 dtex and 1.3 dtex), blended at varying proportions (20%, 40%, and 60%) with **post-industrial waste (PIW)** fibers to produce Ne 30 ring yarn. The research objectives were:

- assess MMCF-Excel fibers' advantages over cotton blends in maximizing PIW content and
- determine optimal MMCF-Excel fiber length and fineness for PIW fiber blending.

3. Raw material and trial set-up

3.1. General

Grasim has supplied three different Excel (Lyocell) fiber types and Recover has supplied 100% cotton PIW (post-industrial waste; bleached) fibers for conducting this trial. The following table shows the key fiber values of the raw materials used in the project.

		R	C	X1	X2	X3
Raw Material		**Cotton PIW (bleached)**	**Virgin cotton**	**Excel (Lyocell)**		
Origin		Recover	Tschad	Grasim - Birla		
Commercial staple; UHML	mm	17	30	38	38	34
Fiber fineness	Mic/dtex	3.8	4	1.3	1	1
Test instrument – Uster AFIS pro						
Commercial staple; UQL (w)	mm	17.1	29.7			
5%-fiber length (n)	mm	20.7	36.5			
Mean fiber length L (n)	mm	8.8	18.9			
Short fiber content < 12.7 mm (n)	%	77.9	29.5			
Fiber neps	1/g	1007	197			
Seed coat neps	1/g	50	12			

3.2. Raw materials and blends

Raw materials

Recover	Birla Excel (Lyocell)			Virgin cotton
Cotton PIW (bleached) **R**	38 mm, 1.3 dtex **X1**	38 mm, 1 dtex **X2**	34 mm, 1.3 dtex **X3**	**C**

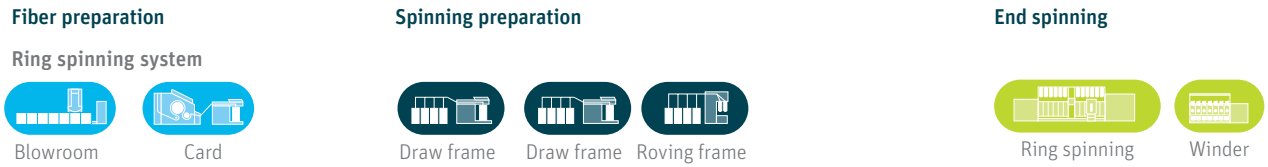
Blends

R/X1 20/80%, 40/60%, and 60/40%	**R/X2** 20/80%, 40/60%, and 60/40%	**R/X3** 20/80%, 40/60%, and 60/40%	**R/C** 20/80%

3.3. Spinning plan – Ne 30 ring yarn

In fiber preparation, the precision blender UNIblend A 81 was used for achieving precise and homogenous blending for all blend positions. The standard process with two draw frame passages was adopted to ensure an optimal draft distribution up to the roving frame. As a result, a better control of the short-fiber movement is achieved.

Spinning process – standard two draw frame passage process



	Machine	Type	Infeed ktex/Ne	Doublings	Draft	Output ktex/Ne tex/Ne	Production speed m/min, rpm	Remarks
Fiber preparation	Opening & Cleaning	A 11- B 12 - B 3/4						for cotton
	Opening	B 3/4						for Excel
	Opening	B 36						for PIW
	Blending & Opening	A 81 - A 79						for all blends
	Card	C 80			100	6/0.1		60 kg/hr
Spinning preparation	Drawframe 1st passage	SB-D 50	6/0.1	4	4	6/0.1	600	Optimize drafts & distances
	Draw frame 2nd passage	SB/RSB-D 50	6/0.1	5	5.88	5.1/0.116	500	
	Roving	F 39	5.1/0.116	1	7.75	656/0.9	1 000	Ne 30
End spinning	Ring	G 35	656/0.9	1	33.3	19.7/30		

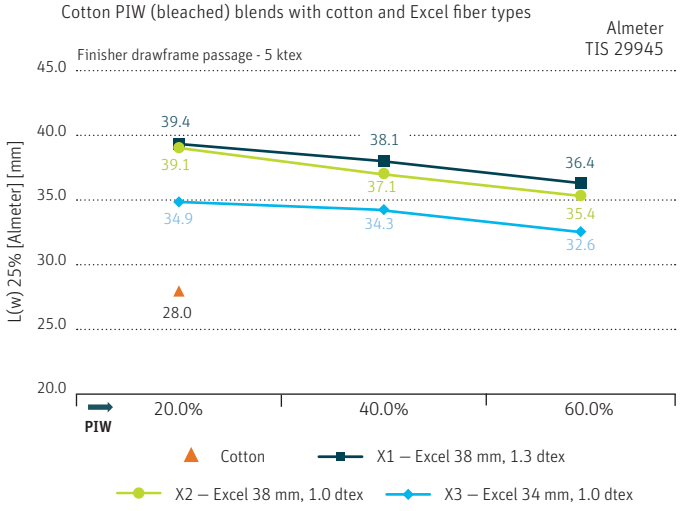
4. Blending Recover recycled cotton (PIW) with different Excel fibers

4.1. Fiber properties

What impact does it have on the fibers properties if the Recover recycled cotton fibers (PIW) are blended with the Excel fibers instead of virgin cotton fibers? The cotton blend with 80% virgin fibers and 20% recycled fibers (PIW) serve as a reference. The fiber lengths of the Excel fiber blends showed a decreasing trend with increasing PIW content but were significantly higher compared to the reference cotton blend. Obviously, the shorter Excel fiber (34 mm) showed relatively lower fiber length compared to the longer Excel fiber (38 mm) types in the blend.

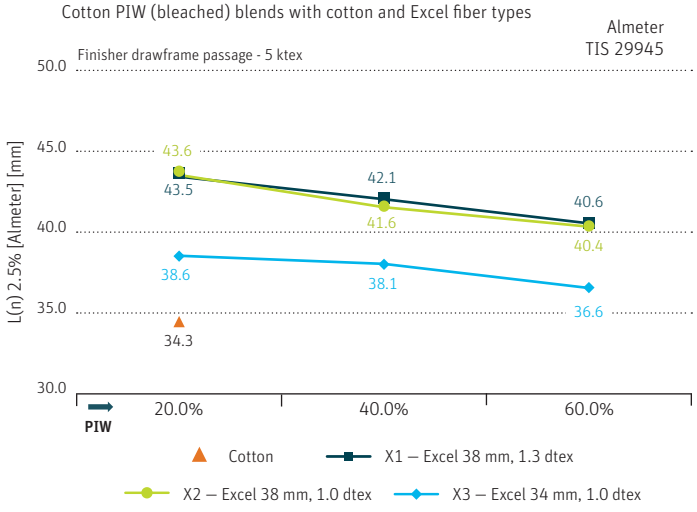
Fiber length L(w) 25%: Impact of PIW blend ratios

Cotton PIW (bleached) blends with cotton and Excel fiber types

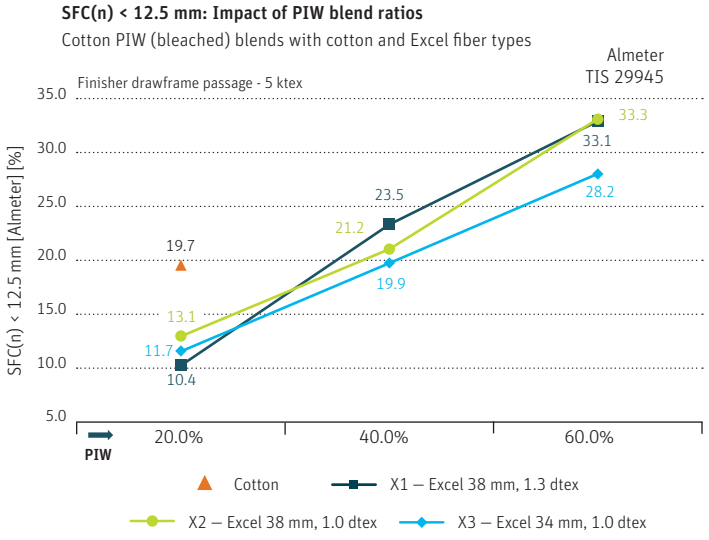


Fiber length L(n) 2.5%: Impact of PIW blend ratios

Cotton PIW (bleached) blends with cotton and Excel fiber types



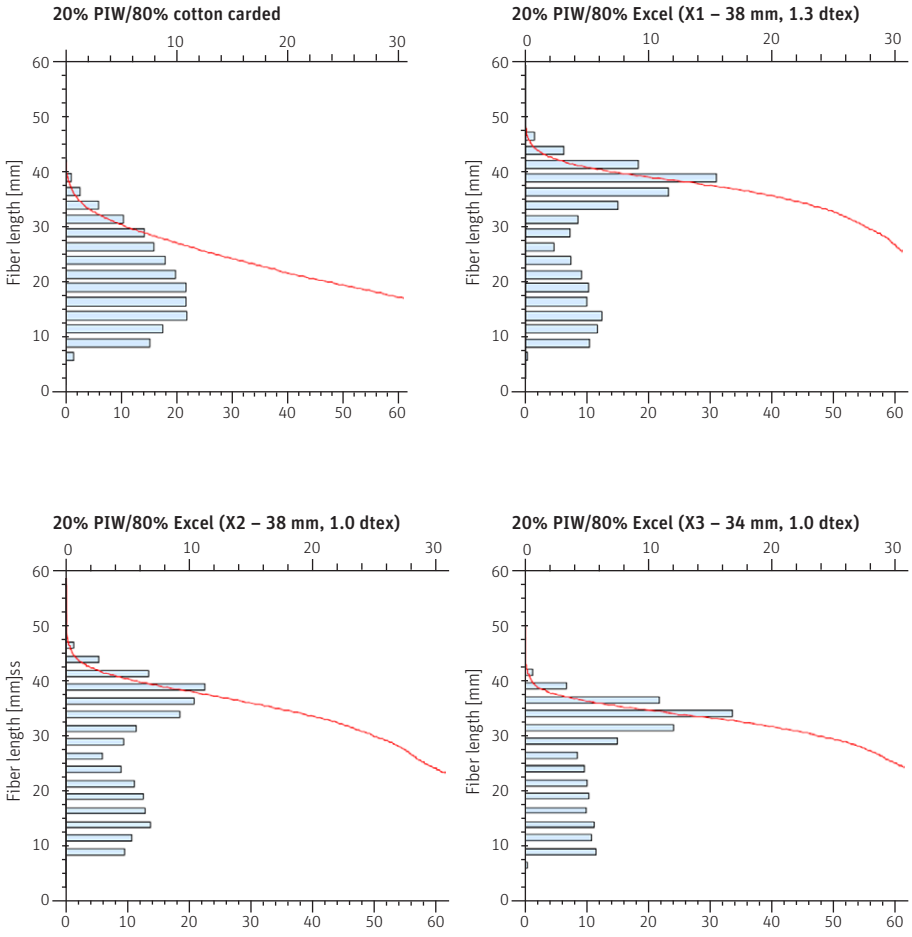
The short-fiber content of all the Excel fiber blends, at 20% PIW content, were significantly lower compared to the reference cotton blend and showed an increasing trend with increasing PIW content. Among the three Excel fiber types the shorter and finer Excel (34 mm 1.0 dtex) fiber blend showed significantly lower short-fiber content even at higher PIW content and matched also with the reference cotton blend at 40% PIW .



4.2. Fiber distribution – compatibility of Excel fibers with PIW

The fiber length histograms of the Excel blends were analyzed to understand the fiber distribution and to define a suitable fiber type to blend with PIW fibers which could be an advantage over cotton. The aim was to get a narrower fiber distribution similar to that of a cotton blend but with better fiber lengths.

The histogram photos of the 20% PIW blends reveal that the shorter Excel fiber (34 mm) exhibits narrow and even fiber distribution when compared to longer Excel fibers (38 mm). The shorter fiber length combined with better fiber distribution enabled shorter drafting distances and even better fiber control compared to the cotton blend.



On the other hand, the longer Excel fibers (38 mm), with wider and uneven fiber distribution, tend to form more fiber packages during drafting resulting in higher unevenness.

4.3. Yarn quality – Ne 30 ring yarn

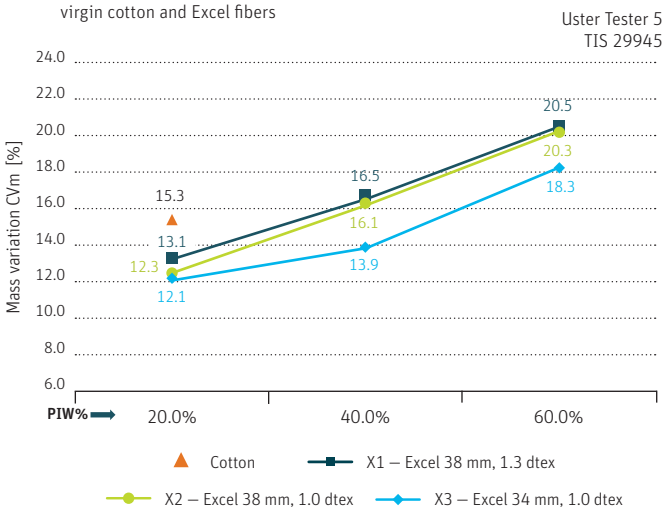
The positive impact realized in the fiber and spinning preparation stages with the Excel fiber blends with PIW fibers was further studied in the yarn stage by spinning the blends to Ne 30 ring yarn.

As expected, the yarn quality showed an inferior trend with increased PIW content in the blend with all the Excel fiber types.

Yarn unevenness

The yarn unevenness of the shorter Excel fiber (34 mm) blend, directly influenced by the even and narrow fiber length distribution, was significantly lower up to 40% PIW content when compared to reference cotton blend and relatively lower than the longer Excel fibers (38 mm).

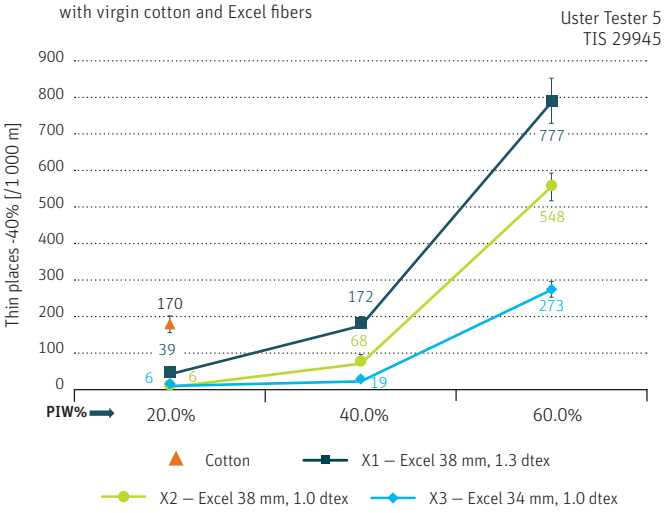
Unevenness: Impact of PIW blend ratios with Excel fibers
Ne 30 Ring yarn, Recover recycled cotton (PIW) blended with virgin cotton and Excel fibers



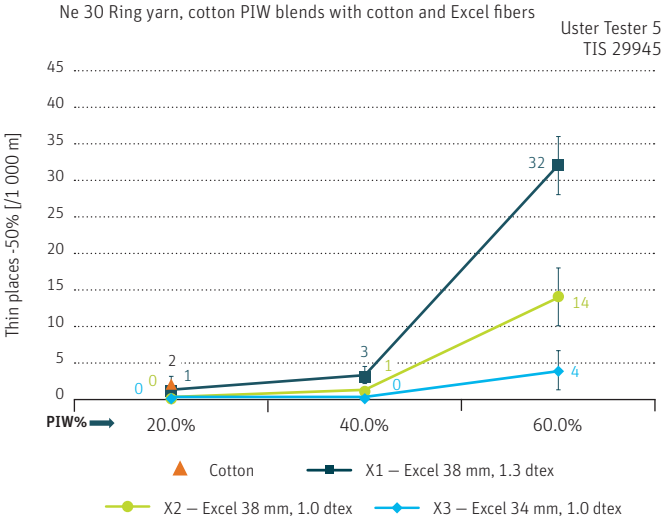
Yarn imperfections – thin places

The yarn thin places of all the Excel fiber blends were better with up to 40% PIW content when compared to the reference cotton blend but significantly increased at higher PIW content. Influenced by a higher amount of fibers in the cross section (Excel: 1.3 dtex vs. 1.0 dtex), the finer Excel fiber blends showed less thin places. With shorter fiber length (Excel: 34 mm vs. 38 mm) the thin places were significantly lower even at highest PIW content of 60%.

Thin -40%: Impact of PIW blend ratios with Excel fibers
Ne 30 Ring yarn, Recover recycled cotton (PIW) blended with virgin cotton and Excel fibers



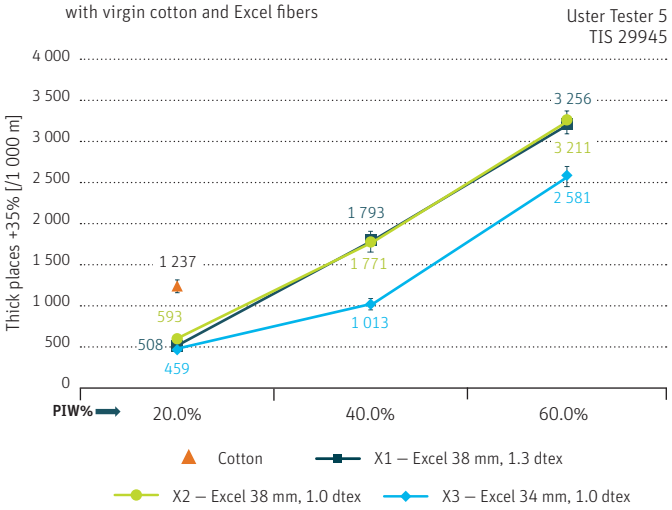
Thin -50%: Impact of PIW blend ratios with Excel fibers
Ne 30 Ring yarn, cotton PIW blends with cotton and Excel fibers



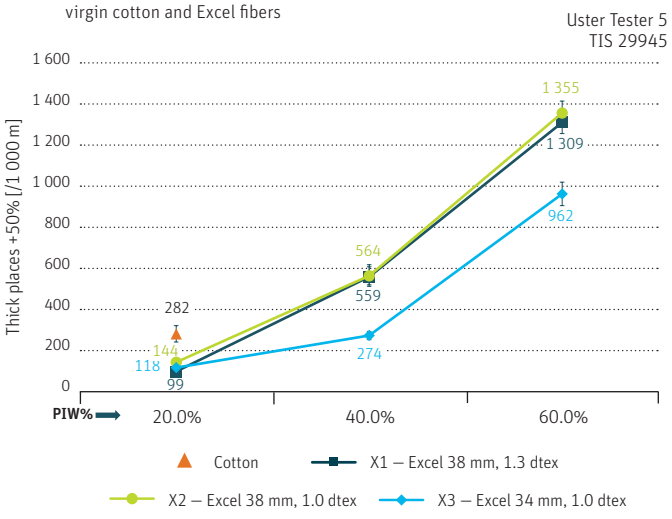
Yarn imperfections – thick places

The yarn thick places, mainly influenced by the fiber length, showed a similar trend as the unevenness. The shorter Excel fiber (34 mm) blend showed less thick places up to 40% PIW content when compared to the reference cotton blend and relatively less compared to the longer Excel fibers (38 mm).

Thick +35%: Impact of PIW blend ratios with Excel fibers
Ne 30 Ring yarn, Recover recycled cotton (PIW) blended with virgin cotton and Excel fibers



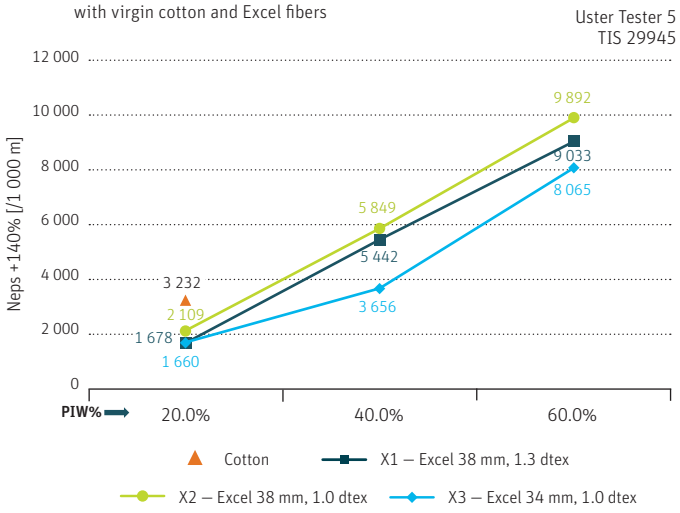
Thick +50%: Impact of PIW blend ratios with Excel fibers
Ne 30 Ring yarn, Recover recycled cotton (PIW) blended with virgin cotton and Excel fibers



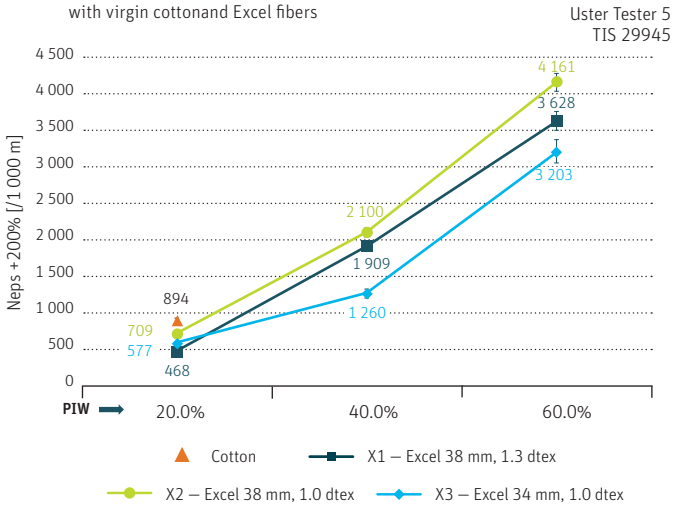
Yarn imperfections – neps

The yarn neps were not much influenced by the length and fineness properties of the Excel fibers. With 20% PIW the neps (+140% and +200%) were slightly better with all the Excel fiber blends. Interestingly, the longer and finer Excel fiber (38 mm, 1.0 dtex) blend showed the highest number of neps of all the Excel fiber types.

Neps +140%: Impact of PIW blend ratios with Excel fibers
Ne 30 Ring yarn, Recover recycled cotton (PIW) blended with virgin cotton and Excel fibers



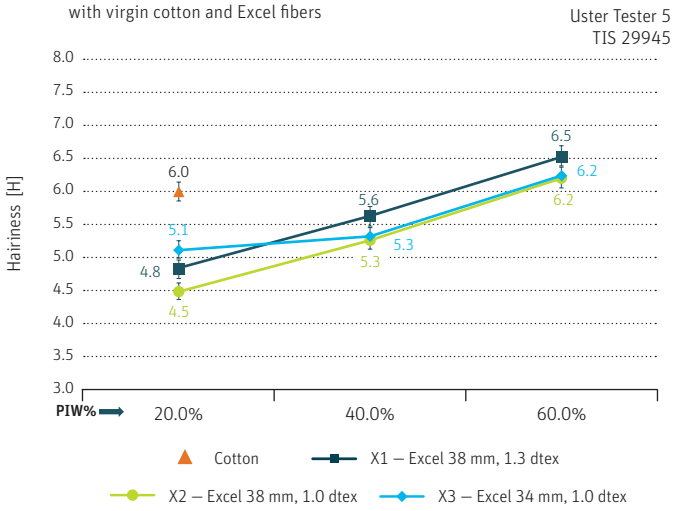
Neps +200%: Impact of PIW blend ratios with Excel fibers
Ne 30 Ring yarn, Recover recycled cotton (PIW) blended with virgin cottonand Excel fibers



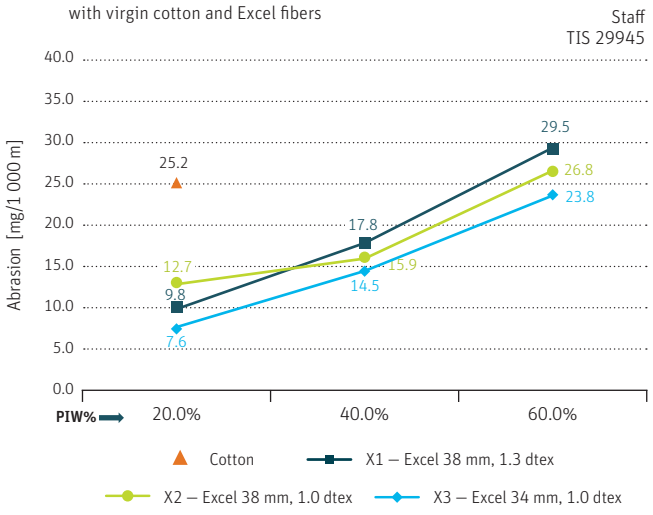
Yarn hairiness and abrasion

The yarn hairiness and abrasion of all the Excel fiber blends was significantly better up to 40% PIW content when compared to the reference cotton blend. The finer Excel fiber (1.0 dtex) blends showed better hairiness and abrasion while the shorter and finer fiber (34 mm, 1.0 dtex) blends showed the lowest abrasion indicating a better fiber integration in the yarn structure.

Hairiness: Impact of PIW blend ratios with Excel fibers
Ne 30 Ring yarn, Recover recycled cotton (PIW) blended with virgin cotton and Excel fibers



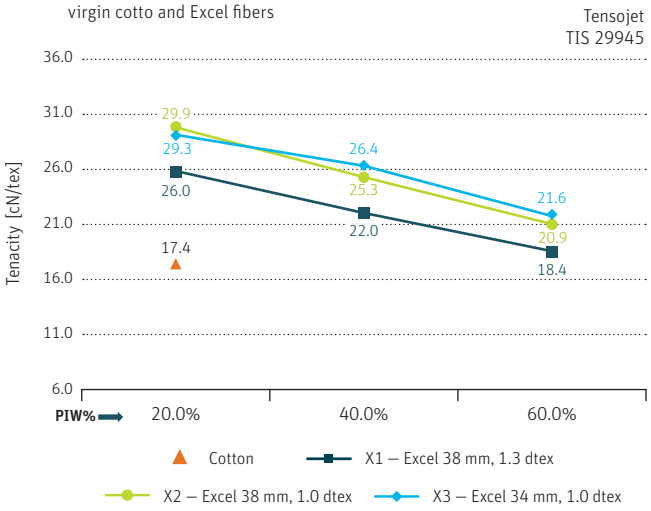
Abrasion: Impact of PIW blend ratios with Excel fibers
Ne 30 Ring yarn, Recover recycled cotton (PIW) blended with virgin cotton and Excel fibers



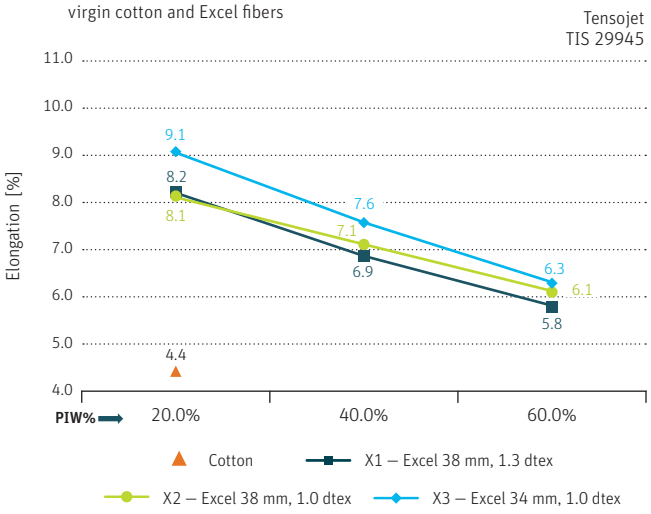
Yarn tenacity and elongation

The tensile properties, both tenacity and elongation, benefited from the fiber length and strength of the Excel fibers. They were significantly higher even at the highest PIW content of 60% when compared to the reference cotton blend. While the finer Excel fiber blends showed better tensile values, the shorter and finer Excel fiber blend showed the highest of all Excel fiber types.

Yarn tenacity: Impact of PIW blend ratios with Excel fibers
Ne 30 Ring yarn, Recover recycled cotton (PIW) blended with virgin cotto and Excel fibers



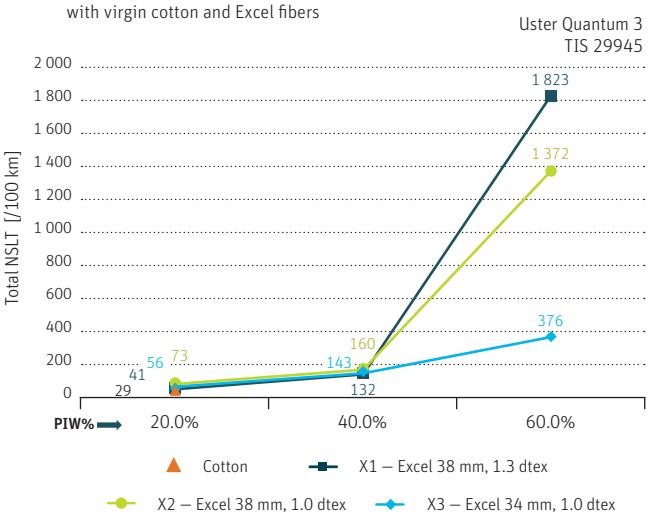
Yarn elongation: Impact of PIW blend ratios with Excel fibers
Ne 30 Ring yarn, Recover recycled cotton (PIW) blended with virgin cotton and Excel fibers



Yarn fault cuts – Uster Quantum 3

The yarn quality cuts (NSLT – Neps, short thick, long thick and long thin) at the winding machine were similar at 20% PIW content with all the Excel fiber blends when compared to the reference cotton blend. The quality cuts showed a similar trend up to 40% PIW content but then increased exponentially while the shorter Excel fiber was still significantly better than the other two Excel fibers.

NSLT cuts: Impact of PIW blend ratios with Excel fibers
Ne 30 Ring yarn, Recover recycled cotton (PIW) blended with virgin cotton and Excel fibers

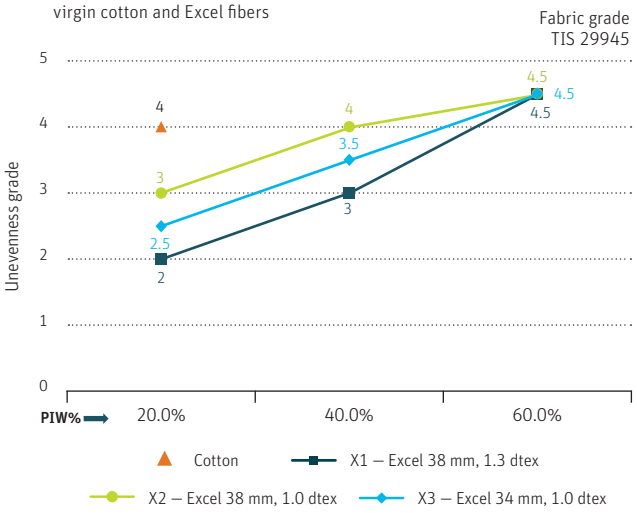


4.4. Fabric quality – single jersey knitting

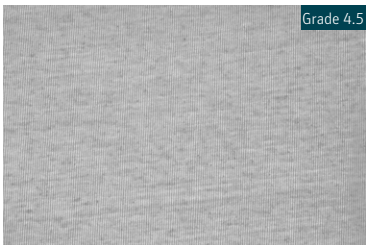
The fabric appearance was graded based on the unevenness, thick and thin places and neps on the fabric surface. The grade scale is rated from 1 to 5 with 1 = Excellent and 5 = Poor.

The fabric appearance/unevenness of the Excel fiber blends was better up to 40% PIW blend compared to the reference cotton blend. The visual grading and comparison of the fabrics under transmitted light source also confirms this.

Fabric appearance: Impact of PIW blend ratios with Excel fibers
Ne 30 Ring yarn, Recover recycled cotton (PIW) blended with virgin cotton and Excel fibers



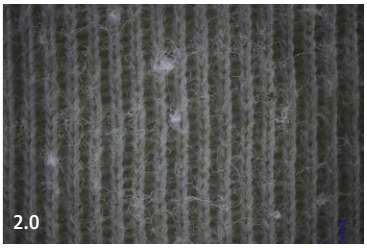
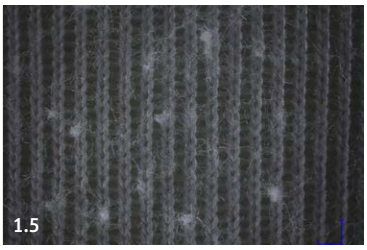
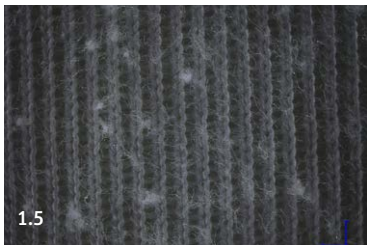
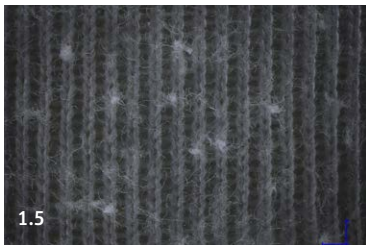
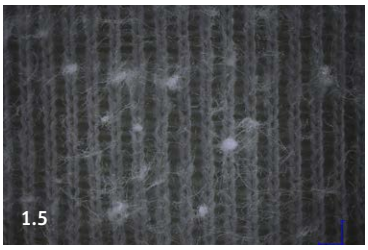
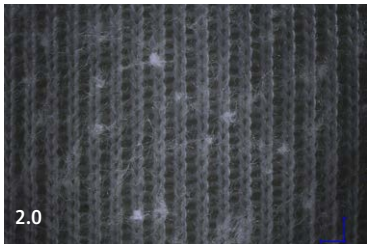
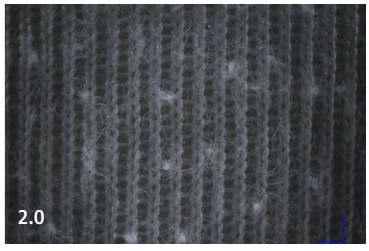
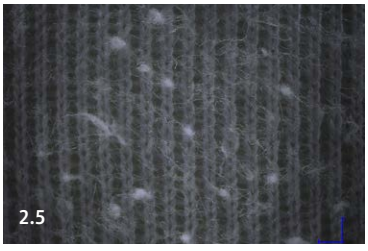
Fabric appearance/unevenness

	20% PIW/80% virgin cotton (carded)		
	 Grade 4		
	20% PIW/80% Excel fibers	**40% PIW/60% Excel fibers**	**60% PIW/40% Excel fibers**
X1	 Grade 2	 Grade 3	 Grade 4.5
X2	 Grade 3	 Grade 4	 Grade 4.5
X3	 Grade 2.5	 Grade 3.5	 Grade 4.5

Fabric pilling grade

The results from the Martindale pilling tests of the grey fabrics were compared at 7 000 cycles. The fabric pilling tendency/grade was similar or better with Excel fiber blends up to 40% PIW content compared to the reference cotton blend.

Pilling appearance and grade at 7 000 cycles

	20% PIW/80% virgin cotton		
	 2.0		
	20% PIW/80% Excel fibers	**40% PIW/60% Excel fibers**	**60% PIW/40% Excel fibers**
X1	 1.5	 1.5	 1.5
X2	 1.5	 1.5	 1.5
X3	 2.0	 2.0	 2.5

5. Conclusion & Outlook

The primary barriers to incorporating mechanically recycled cotton fibers into yarn production are the elevated short-fiber content and the increased fiber nep count.

The high short-fiber content, inherent in recycled cotton blends, can be significantly reduced by replacing virgin cotton with man-made cellulosic fibers (MMCFs). These synthetic alternatives offer superior fiber length consistency and fineness uniformity with virtually no short-fiber content. This substitution simultaneously enhances yarn quality, improves spinning efficiency, and optimizes downstream processing performance. Importantly, the resulting yarns maintain their 100% cellulosic composition and preserve the characteristic cotton feel when mechanically recycled cotton fibers are incorporated.

Contrary to intuitive expectations, the research reveals that shorter (and finer), rather than longer, MMCFs achieve superior results in recycled cotton applications. Longer fiber cuts require wider drafting system distances, which allows the shorter recycled cotton fibers to create more irregularities. This leads to increased thin and thick places and greater yarn unevenness. These findings provide a clear pathway for MMCF manufacturers like Birla to optimize their cutting specifications, ensuring that MMCF-recycled cotton blends can achieve fiber length distributions comparable to virgin cotton.

While MMCF integration effectively resolves the short-fiber challenge, nep content remains a significant concern. The yarn results in this study have shown that thick places and nep level remain elevated with a higher mechanically recycled fiber share.

The pre-carding technology which is a part of Rieter's recycling toolbox for the manufacturing of high quality ring yarns, can be a solution to reduce these disturbing impurities.

The study confirms that Birla Excel fibers show clear advantages when blended with mechanically recyled cotton (PIW) fibers from Recover compared to a traditional blend of recycled and virgin cotton. With consistent fiber cut length and fineness properties compared to cotton, the Excel fibers enabled an increase of the PIW content while still maintaining the final yarn and fabric quality.

Of the three Excel fiber types, the shorter and finer Excel fiber (34 mm, 1.0 dtex) performed well even at higher PIW content up to 40% compared to the reference cotton blend with 20% PIW. The shorter fiber cut length matched well with the PIW fibers, thus improving the fiber length distribution and processability. The finer fibers improved the integrity of the yarn structure leading to better surface and performance characteristics.

The following inferences are made based on the findings from this project.

- With its consistent fiber properties, MMCFs (Excel fibers) are an excellent virgin cellulosic option for blending with mechanically reclycled cotton fibers.
- Shorter and finer MMCFs, preferably in the range of 30 to 32 mm, are a more suitable match than longer fibers for mechanically recycled PIW fibers.
- With a suitable MMCF the mechanical recycled PIW content can be considerably increased up to 50% which is more than twice as much as in a cotton blend.

We want to thank the project partners for their great support during this study and look forward to the next joint projects, to further increase the share of both MMCFs and mechanically recycled fibers in the raw material mix of the future.

6. Notes

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