Abir Chakrabarti
Birla Cellulose (TRADC)
Kharach, India

Dr. Aspi N Patel
Aditya Birla Group
Mumbai, India

Harald Schwippl
Rieter Machine Works Ltd.
Winterthur, Switzerland

September 2020

New Possibilities with Air-Jet Spinning Using Spun-Dyed Viscose Fibers

Contents

1. Air-Jet Spinning of Spun-Dyed Viscose

The need for sustainability and environment-friendly manufacture of textiles across the entire value chain from the fibers over the staple fiber yarn to knitted or woven fabric, right up to the finishing of the textile fabric is increasing constantly. Dyeing natural and synthetic cellulose fibers already during the fiber manufacturing instead of the complex and expensive dyeing process of the textile fabric is an approach to support this trend. However, it is important, that the color pigments do not cause any adverse effects on the textile fabric during the spinning process of the staple fibers.

Due to continuous development of machines and technology, air-jet spinning opens new and additional possibilities for yarn produced from natural cellulose such as viscose, natural fibers, and their blends. Spun-dyed viscose fibers have different characteristics depending on their color. This special print summarizes the results of the trial for the manufacturing of spun-dyed viscose fibers in the colors black, violet, and yellow with different yarn counts with the air-jet spinning machine J 26 (Fig. 1). Viscose in raw white and the conventional ring spinning system served as a basis for comparison. In order to be able to assess the yarn quality holistically, knitted and woven fabrics have been produced as well.

Slivers Made of Spun-dyed and Undyed Viscose Fibers
100% Viscose, 1.3 and 1.45 dtex, 38 mm

Source: TIS 26258/Technology & Process Analytics

Fig. 1: Dyeing fibers already during fiber manufacturing has a lower environmental impact.

Air-jet spinning has only minimal frictional forces between the fibers with the color pigments and technology components of the machine. This trial tested if this results in lower fiber stress than ring spinning. In ring spinning, frictional forces are exerted on the fibers due to the “ring traveler principle”, in rotor spinning through the fiber separation at the opening roller. The focus in this trial was the quality of the fabric and the performance of the preparation process.

2. Natural Cellulose Fibers on the Rise

Cotton and synthetics are still the dominant fibers but the worldwide demand for fibers made from naturally renewable raw materials is growing. Till date, the worldwide production of staple fibers from natural cellulose has reached over 6 million tons (Fig. 2).

How is viscose produced? Cellulose fibers come from the bark, wood or leave of plants. The plant-based material is crushed and dissolved in chemicals. The pulp which results from this process is then pressed into sheets. The manufacturers of viscose fibers dissolve these pulp sheets again, extract the fibers and make them ready for further processing. Under consideration of the manufacturing method, these cellulose fibers are subdivided into viscose, modal, and lyocell. Viscose is one of the most common "manufactured" cellulose fibers.

Staple Fiber Production Worldwide

Different Raw Materials

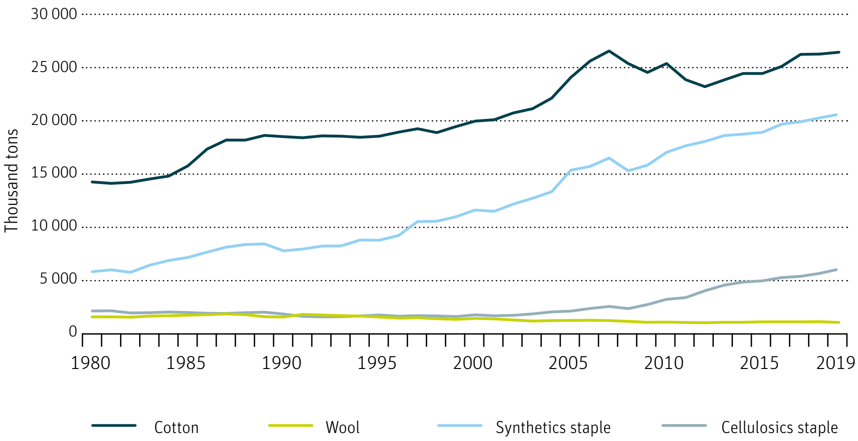


Fig. 2: The production of natural cellulose fibers is growing since 2002. Source: Wood Mackenzie

Depending on the range of application, the fiber types differ in

- their physical characteristics such as tenacity
- their structure such as cross-sectional shape and thus the fabric touch
- their capacity to retain and release moisture
- their dyeing

Viscose and air-jet spinning have already many advantages, such as low pilling characteristics. If there is a stable and optimized spinning system to process spun-dyed viscose, the result is a new textile product with unique benefits such as highest efficiency, reduced environmental impact, lower yarn manufacturing costs and better quality for the end user.

3. Raw Material and Trial Setup

Grasim Industries Limited, located in India and belonging to the Aditya Birla Group (ABG), is one of the largest manufacturers of viscose fibers. Grasim and Rieter have a joint cooperation to explore the production of best quality air-jet spun yarns and fabrics made from viscose fibers and its blends.

For this trial Grasim and Rieter tested the impact of different spinning systems on spinning dyed viscose fibers to define the ideal spinning process as well as the advantages and risks.

Viscose fiber characteristics depend among others on color pigments. Different color could thus influence the yarn quality. However, this trial focuses on the benefits of air-jet spinning of spun-dyed fibers in general. Different colors have been used to get a holistic picture and not to differentiate between the colors.

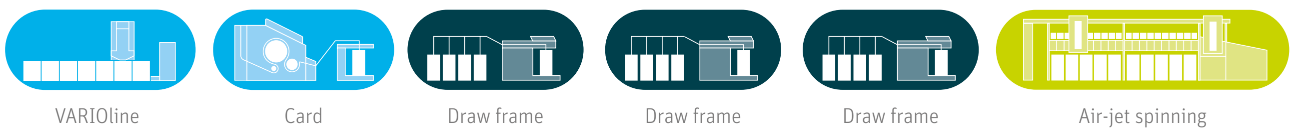
The following table shows the key fiber values. The fiber count for spun-dyed viscose was, with 1.45 dtex, coarser than that of raw white viscose with 1.3 dtex.

Key Fiber Values for Undyed and Spun-Dyed Fibers

Color	**Undyed**	**Black**	**Violet**	**Yellow**
Raw material	Viscose	Viscose	Viscose	Viscose
Cut length/ staple classing [mm]	38	38	38	38
Fiber count [Mic.]/[dtex]	1.3	1.45	1.45	1.45
Commercial staple; L25% (w) [mm]	38.7	39.5	38.8	38.9
Mean fiber length (n) [mm]	33.8	33.5	32.2	33.8
Short-fiber content < 12.5 mm (n) [%]	1.1	1.7	6.5	2.8
Neps [1/g]	37	50	30	36
Strength [cN/tex]	27.2	26.3	23.9	24.0

Process Sequences Selected for the Trial

Air-jet spinning process for carded yarn



Ring spinning process for carded yarn

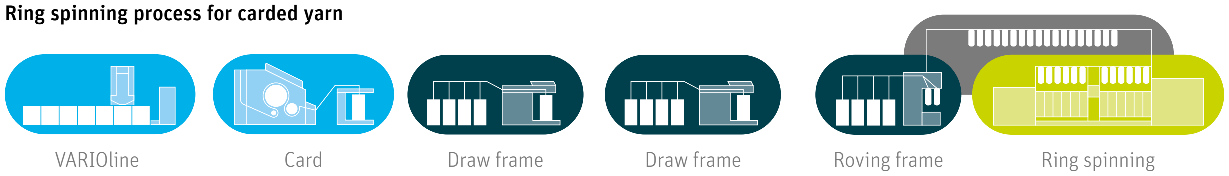


Fig. 3: Two processes were defined for the trial.

Due to the different friction conditions of the varying viscose raw materials, the card production was selected with only 60 kg/h to ensure a gentler carding process. According to current findings, the card production of modern high-performance cards is at around 80–85 kg/h for an optimal processability with raw white viscose.

Four different yarn counts (Ne 24, Ne 30, Ne 40 and Ne 50) were spun with each color.

Spinning Plan of the Air-Jet Spinning Process for Coarse Yarn Counts

Machine	Type	Feed [tex]	Doubling [fold]	Draft [fold]	Output [tex]	Delivery [m/min]	Comment
Blowroom	A 11 – B 3/4 (Mixing bale opener) – A 79 – Chute feed						
Carding	C 70		1	100	6 000		60 kg/h
Draw frame 1	SB-D 15	6 000	6	7.2	5 000	650	
Draw frame 2	SB-D 15	5 000	5	6.25	4 000	400	
Autoleveler draw frame	RSB-D 40	4 000	6	6.0	4 000	400	
Air-jet spinning machine	J 26	4 000	1	136	29.6	350	
Air-jet spinning machine	J 26	4 000	1	204	19.6	350	

Spinning Plan of the Air-Jet Spinning Process for Fine Yarn Counts

Machine	Type	Feed [tex]	Doubling [fold]	Draft [fold]	Output [tex]	Delivery [m/min]	Comment
Blowroom	A 11 – B 3/4 (Mixing bale opener) – A 79 – Chute feed						
Carding	C 70		1	100	6 000		60 kg/h
Draw frame 1	SB-D 15	6 000	6	7.2	5 000	650	
Draw frame 2	SB-D 15	5 000	5	6.25	4 000	400	
Autoleveler draw frame	RSB-D 40	4 000	4	7.0	2 300	400	
Air-jet spinning machine	J 26	2 300	1	156	14.7	350	
Air-jet spinning machine	J 26	2 300	1	195	11.8	350	

Spinning Plan of the Ring Spinning Process for Carded Yarn

Machine	Type	Feed [tex]	Doubling [fold]	Draft [fold]	Output [tex]	Delivery [m/min]	Twist [ae] [T/m]	Spindle Speed [rpm]	Comment
Blowroom	A 11 – B 3/4 (Mixing bale opener) – A 79 – Chute feed								
Carding	C 70		1	100	6 000				60 kg/h
Draw frame	SB-D 15	6 000	6	7.2	5 000	650			
Autoleveler draw frame	RSB-D 40	5 000	6	6	5 000	400			
Roving frame	F 15	5 000	1	6.9	720		0.84	1 000	
Ring spinning machine	G 35	720	1	29	24.6	22.6	3.4 655	14 800	Ring Ø 40 mm
Ring spinning machine	G 35	720	1	37	19.6	22.2	3.4 732	16 200	Ring Ø 40 mm
Ring spinning machine	G 35	720	1	49	14.7	20.2	3.4 845	17 000	Ring Ø 40 mm
Ring spinning machine	G 35	720	1	61	11.8	18.0	3.4 946	17 000	Ring Ø 40 mm

4. Spun-Dyed Viscose Fibers and Their Influence on the Spinning Process

With spun-dyed fibers, the color pigments are already a part of the spinning solution and are equally distributed in the spin emulsion. The advantages of this procedure are a higher washing resistance and a better lightfastness compared to the subsequent coloring of the fibers, the fabrics or the textiles. This offers benefits in the range of textile apparel along with benefits for technical textiles such as furniture fabrics which are subjected to UV exposure.

The color pigmentation can be recognized particularly well with black coloring agents, both in the fiber cross section and on the surface (Fig. 4 and Fig. 5). The application of black color pigments indicates that more color pigments deposit on the technology components if darker colors are used. Therefore, these might react more sensitively to fiber stress as compared to lighter colors.

Fiber Cross Section

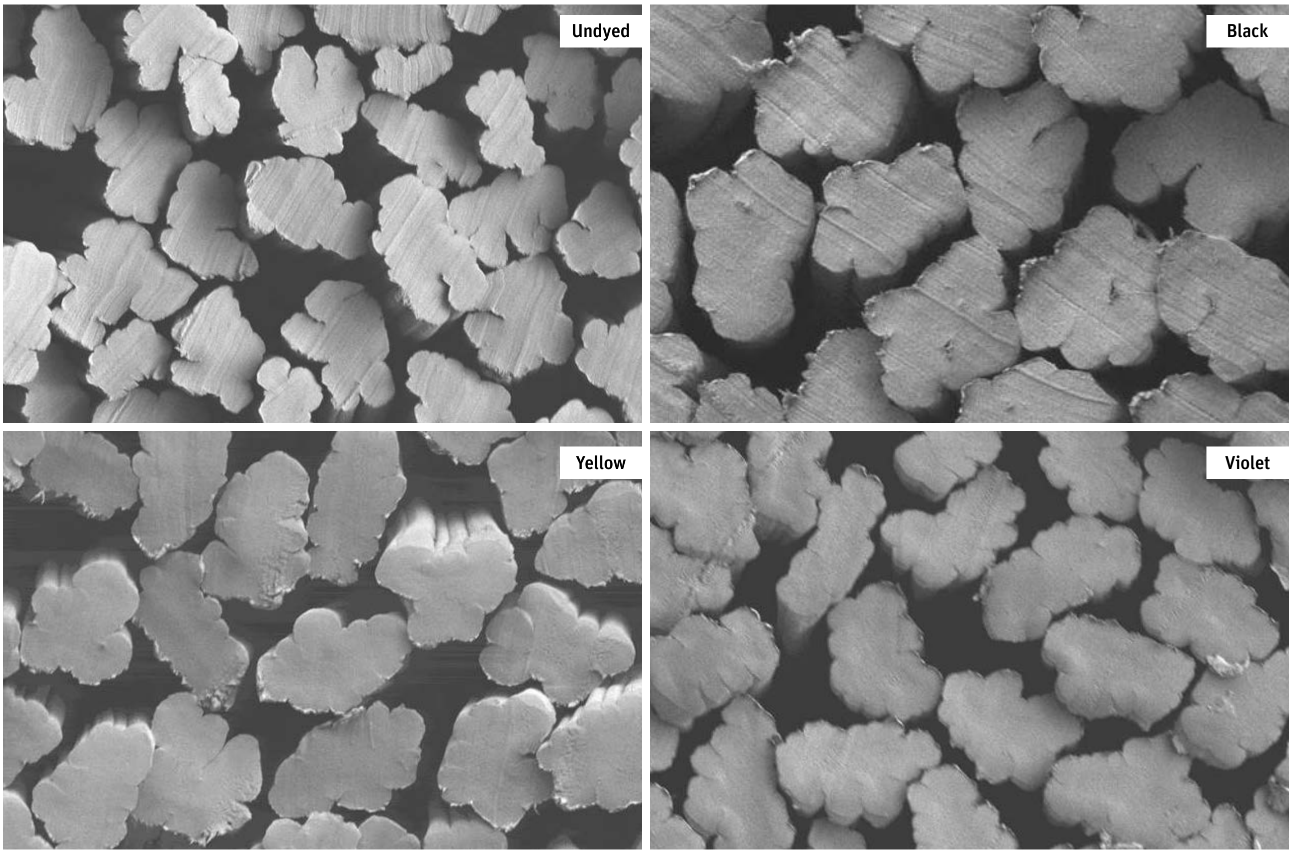


Fig. 4: The graphic shows the cross sections of the viscose fibers in different colors. Source: TIS 26258/Technology & Process Analytics

Color Pigmentation on the Fiber Surface

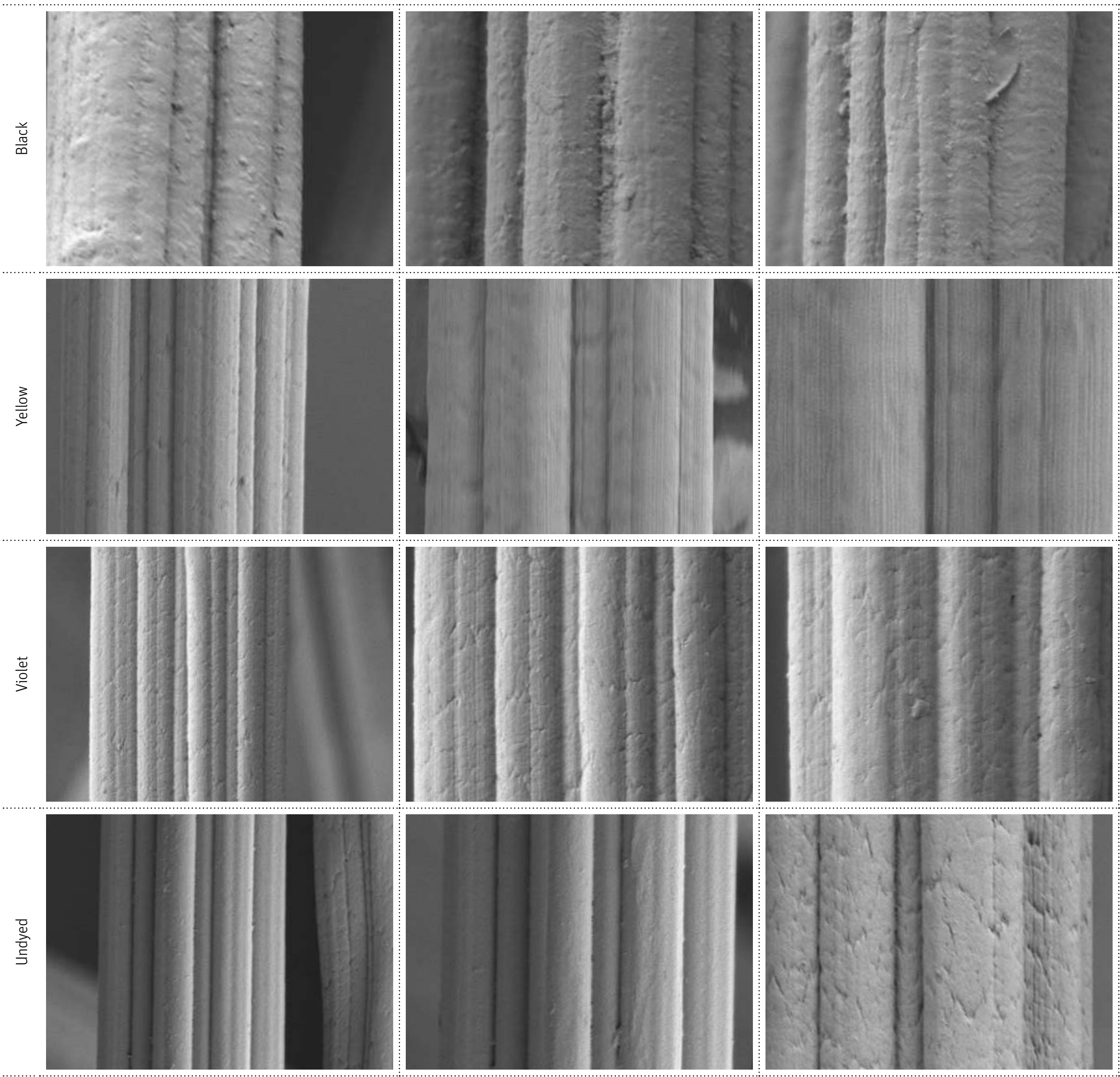


Fig. 5: The surface of the dyed fibers differs depending on the color. Source: TIS 26258/Technology & Process Analytics

The fiber surface picture shows clearly that the black fibers exhibit a very rough fiber surface, which may lead to complications in fiber preparation stage. The black fibers have more particles on the surface and thus a higher fiber-to-fiber friction which is directly proportional to the fiber-metal friction.

The color pigmentation seen in the previous pictures has an influence on the cohesive force. It can be up to 30% higher depending on the color pigmentation. According to Figure 6, the black fibers exhibit a higher fiber-to-fiber friction than the other fibers. If necessary, machine settings such as drafting system distances, fiber mass, or the productivity must be slightly adjusted.

Success can only result from the optimization of the entire system, from manufacturing of the fibers up to the spinning process. A joint system development benefits the whole manufacturing process up to the end user. The processing characteristics in the staple fiber spinning process need to be fulfilled. These are, for instance, all manufacture-relevant criteria such as running characteristics and operating stability on the appropriate system.

New possibilities and approaches are:
• highest efficiency,
• reduced environmental impact,
• lower yarn manufacturing costs and
• better quality for the end user.

Rothschild Cohesive Force over Process Stages (Air-Jet Spinning Process)
100% Viscose, 1.3 and 1.45 dtex, 38 mm

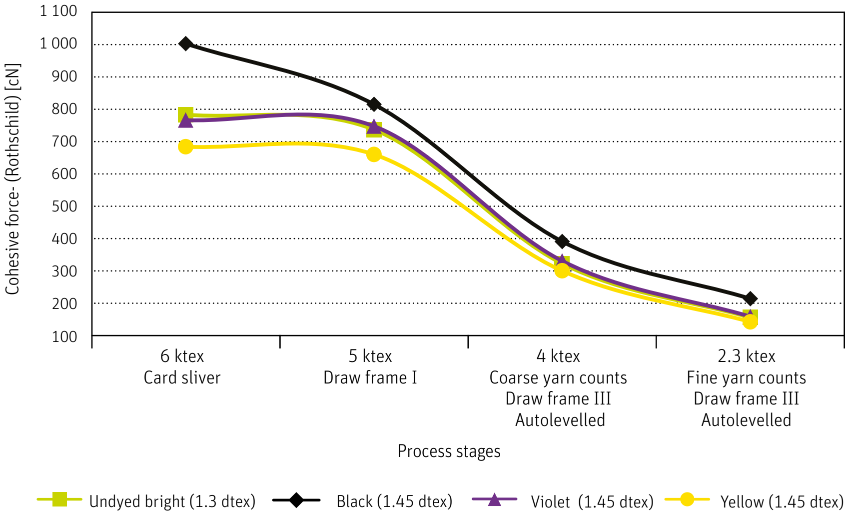


Fig. 6: The cohesive force is higher with black dyed fibers. Source: TIS 26258/Technology & Process Analytics

5. The Importance of Fiber Preparation

5.1. Nep Content

The fiber preparation in the spinning process has a great influence on the processing characteristics on the end spinning machine, especially with air-jet spinning. The important parameters are the optimal fiber opening with minimum fiber neps, a high opening or elimination of the resulting fiber neps by the card, and as few fiber loops as possible at the card delivery unit and the subsequent drafting passages. Every passage where the fibers are merged parallel and temporarily stored for further process stages always includes the risk of fiber loop formation if the machine configuration and settings have not been optimally selected.

The card C 70 showed a very good nep reduction of almost 88% after fiber opening. With less than 10 neps per gram of fiber material, the sliver is perfect for the end spinning process (Fig. 7).

The three drafting passages (see process sequence and spinning plan on page 6 and 7) provided the best evenness in a short- and a long-wave range of the fiber package, without accumulation of fiber loops and with optimal alignment of fiber hooks for air-jet spinning.

An optimal fiber preparation results in a lower ends down rate and a reduced number of clearer cuts on the air-jet spinning machine. This is important for keeping a constant high yarn quality and production efficiency.

Nep Content over Process Stages (Air-Jet Spinning Process)

100% Viscose, 1.3 and 1.45 dtex, 38 mm

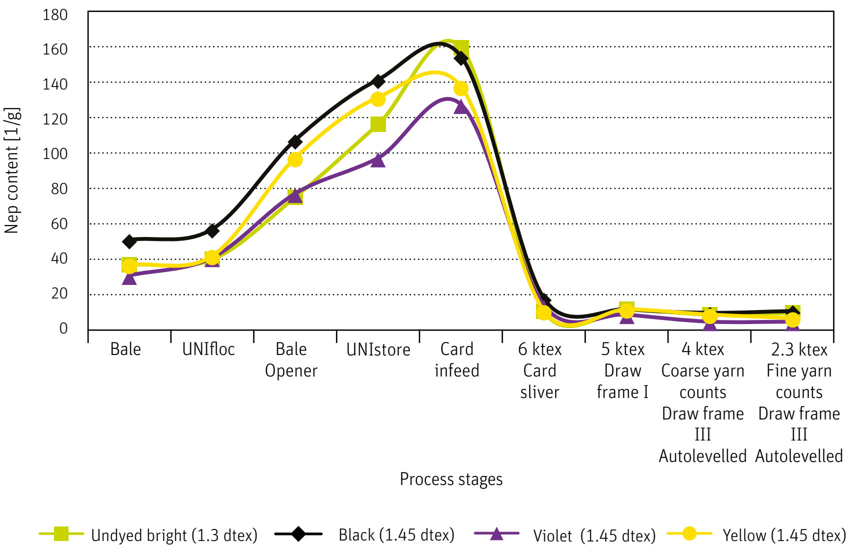


Fig. 7: These process stages ideally prepare the sliver for end spinning. Source: TIS 26258/Technology & Process Analytics

5.2. Fiber Strength and Elongation

The undyed fibers exhibit better strength than the spun-dyed fibers (Fig. 8). This means, the fiber coloration influences the fiber tenacity depending on the pigmentation. Elongation stays almost unchanged.

Color pigments in dope-dyed fiber are solid particulates, and do not deform with fiber. Thus they provide as sites for crack initiation of breakage in the fiber, thereby reducing the fiber strength. Quantity and type of pigment vary with the colors. So fiber strength loss is not identical for each color.

The yarn tenacity is sufficient with all colors, not only for the yarn formation process with air-jet spinning but also for the yarn downstream processing and the end product.

With air-jet spinning, the yarn tenacity is less affected by the fiber strength than in the ring spinning process, due to the different fiber substance yield in the air-jet spinning process.

Fiber Strength and Elongation of Different Viscose Fibers (Air-Jet Spinning Process)

100% Viscose, 1.3 and 1.45 dtex, 38 mm

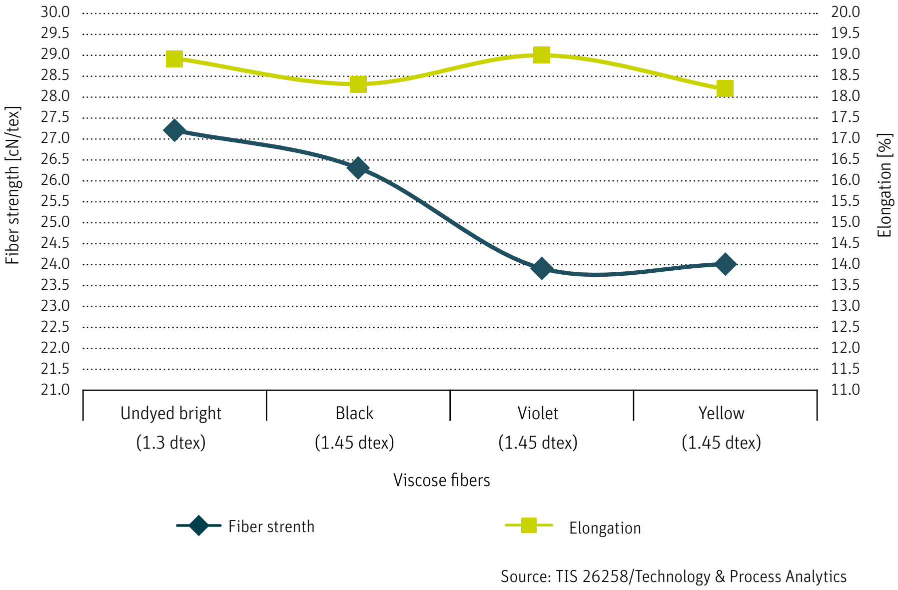


Fig. 8: Fiber strength is lost by dyeing but is still sufficient for all subsequent processes.

6. Yarn Characteristics

6.1. Evenness

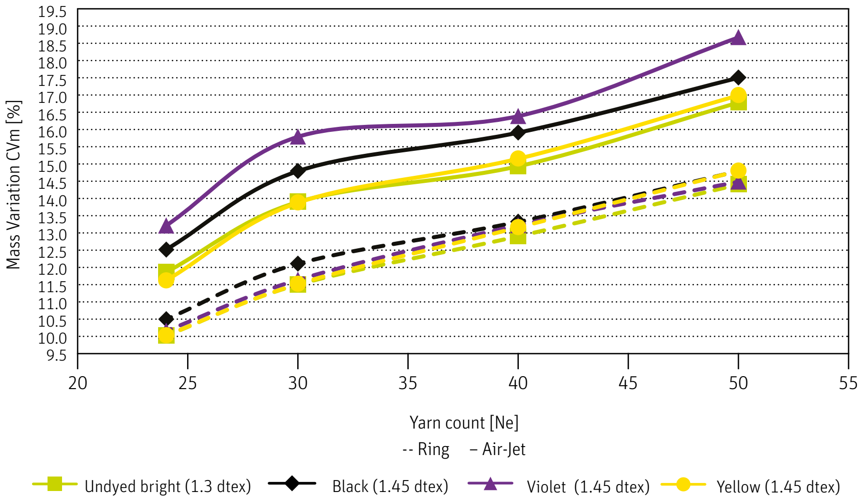
Comparing the unevenness in the short-wave length range of the yarn of air-jet, ring or rotor yarn is not ideal due to the different yarn structure.

In this trial, air-jet and ring yarns were compared to determine the ideal process. In order to obtain a comparison as close to the practice as possible, the quality of the ring yarn was taken after the winding process.

The measured unevenness of air-jet yarns is higher by around 15% due to the yarn structure (Fig. 9). The air-jet yarn also reacts more sensitively to influences such as fiber design and color pigmentation than ring yarn.

Mass Variation of Ring and Air-Jet Viscose Yarns with Respect to Yarn Count

100% Viscose, 1.3 and 1.45 dtex, 38 mm



Source: TIS 26258/Technology & Process Analytics

Fig. 9: The air-jet yarn has a higher unevenness due to its special structure.

6.2. Tenacity and Hairiness

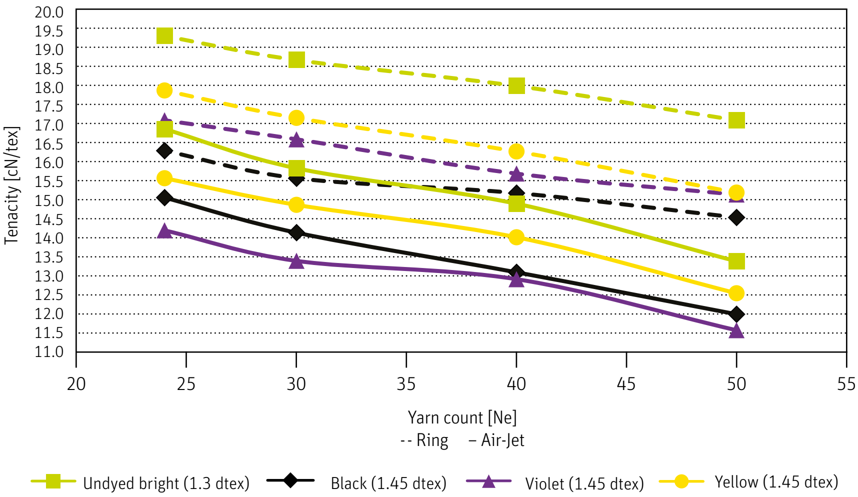
As it could be expected, the yarn tenacity values of air-jet yarn were lower than those of ring yarn (Fig. 10). The requirements for the air-jet yarn that depend on the yarn downstream processing have been, however, completely fulfilled.

The colored air-jet yarn has, depending on the color, a yarn tenacity that is 7 – 14% lower than the raw white. However, all yarns (including black and violet) still meet the requirements for further downstream processing.

Due to its special structure, the air-jet yarn has a unique low hairiness compared to the ring yarn (Fig. 11). It thus has a huge advantage in the functional properties such as pilling and, additionally, a higher color fastness.

Tenacity of Ring and Air-Jet Viscose Yarns with Respect to Yarn Count

100% Viscose, 1.3 and 1.45 dtex, 38 mm



Source: TIS 26258/Technology & Process Analytics

Fig. 10: The tenacity of air-jet yarn is lower; however, the requirements for downstream processing are fulfilled.

Hairiness of Ring and Air-Jet Viscose Yarns with Respect to Yarn Count

100% Viscose, 1.3 and 1.45 dtex, 38 mm

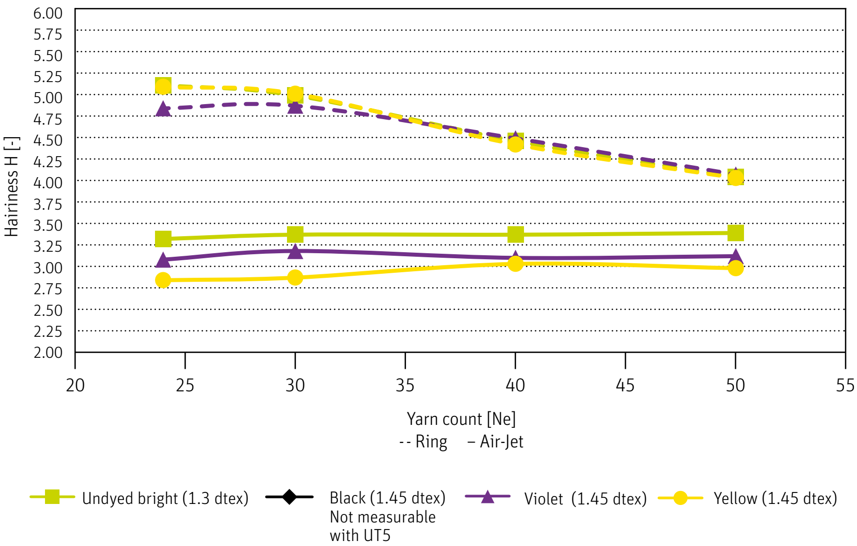


Fig. 11: Air-jet yarns show better results in hairiness.

Source: TIS 26258/Technology & Process Analytics

7. Fabric Characteristics

7.1. Evenness in the Woven Fabric

The examination of the yarns has shown that the ring yarn exhibits better results on all the test criteria except hairiness. But at the fabric stage, this measured yarn evenness of air-jet yarns does not give the full picture of what the fabric will look like. Quite the opposite, a more even appearance in the fabric structure with air-jet yarns can often be identified compared to a ring yarn. The reason for this is the special yarn structure of air-jet yarn, which results from the bigger yarn diameter, the twisted fibers around the core fibers, and the lower hairiness.

In this case and with the processing of spun-dyed fibers, there is another important advantage of air-jet spinning. In the ring spinning system, more fibers along the yarn strand axis are pushed up as a result of a higher fiber-metal friction at the technology components of the ring as well as the traveler and the rewinding process than with air-jet spinning.

This positive effect of air-jet spinning is especially prominent with spun-dyed viscose fibers. These fibers have a highly enhanced evenness in terms of the fabric structure, which is not available with the raw white fibers to this extent. Therefore, it can be concluded that the processing of spun-dyed fibers in combination with the air-jet spinning process creates new and additional benefits (Fig. 12 – 15).

100% Viscose, Woven, Ne 40, Warp: Filament, Weft: Yellow Air-Jet and Ring Yarn

Air-Jet Ring

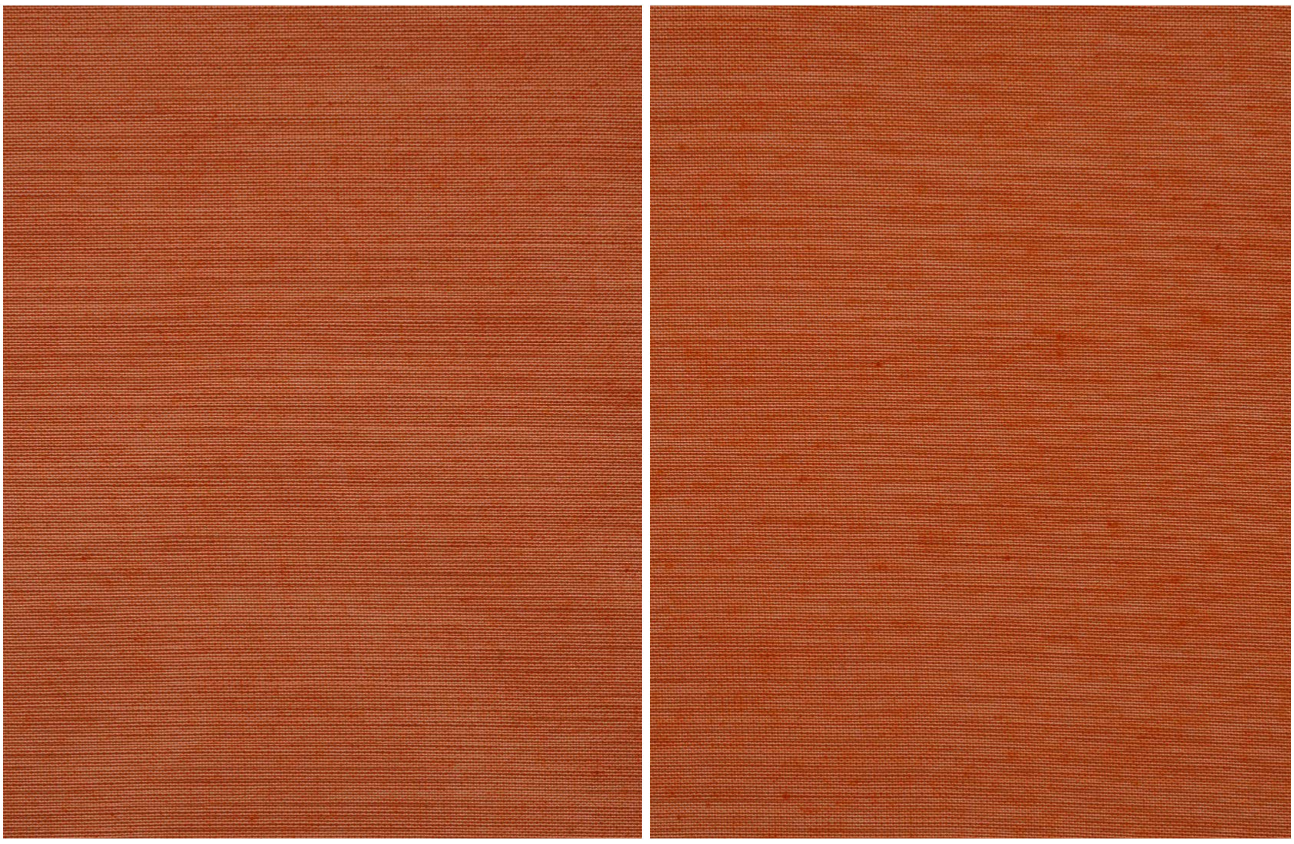


Fig. 12: Although the yarn results showed higher mass variation with air-jet spinning, the fabric shows a superior appearance compared to the ring yarn fabric. Source: TIS 26258/Technology & Process Analytics

100% Viscose, Woven, Ne 40, Warp: Filament, Weft: Violet Air-Jet and Ring Yarn

Air-Jet

Ring

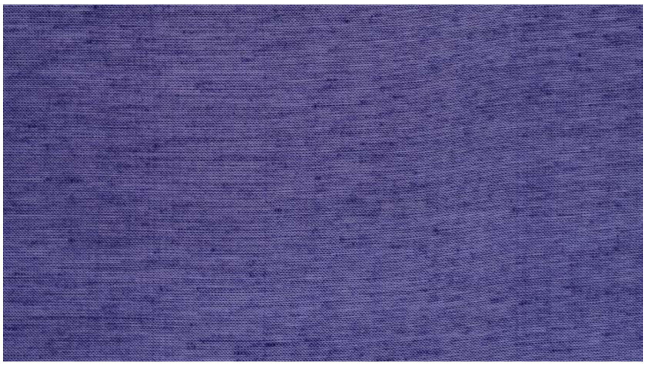


Fig. 13: The combination of air-jet spinning and spun-dyed fibers even creates new benefits which do not occur with undyed fibers. Source: TIS 26258/Technology & Process Analytics

100% Viscose, Woven, Ne 40, Warp: Filament, Weft: Black Air-Jet and Ring Yarn

Air-Jet

Ring

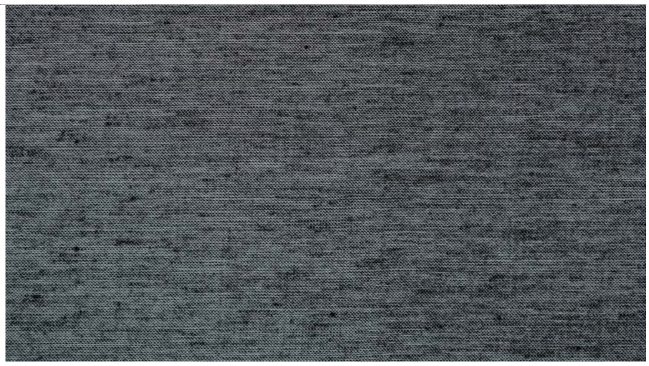
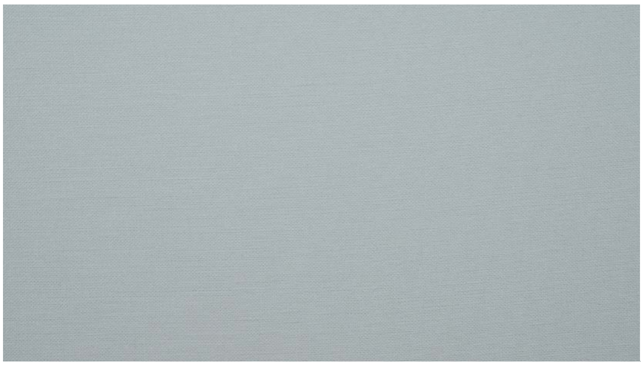


Fig. 14: The black ring yarn fabric shows more nep-like formations. Source: TIS 26258/Technology & Process Analytics

100% Viscose, Woven, Ne 40, Warp: Filament, Weft: Undyed Air-Jet and Ring Yarn

Air-Jet



Ring

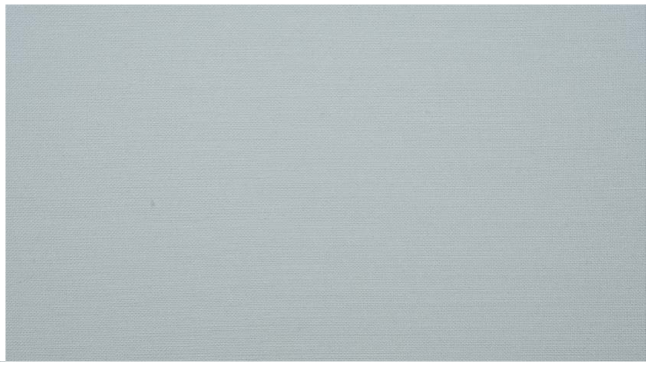


Fig. 15: There is hardly any difference between the raw white fabrics. Source: TIS 26258/Technology & Process Analytics

7.2. Pilling in the Knitted Fabric

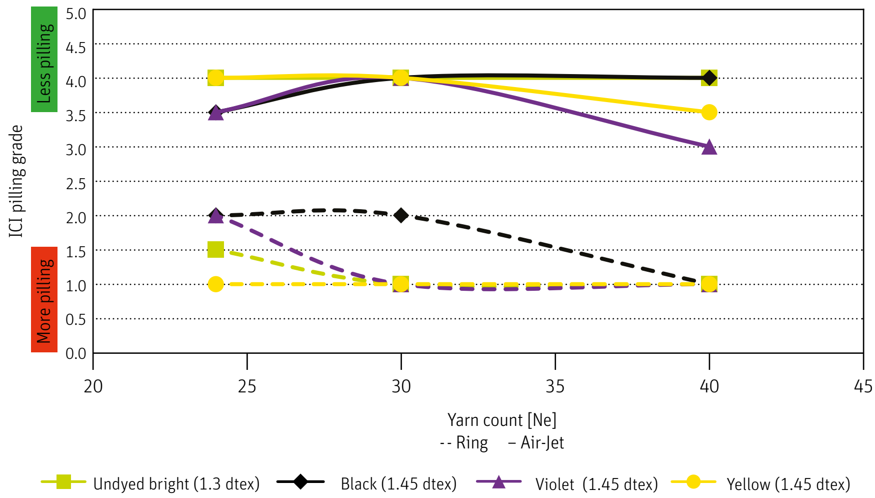
The hairiness in the yarn is a major criterion for pilling formation on the surface of fabrics. The tremendous advantage of air-jet yarn is a lower hairiness – also in combination with spun-dyed fibers.

The air-jet yarn structure thus has a huge advantage in the functional properties such as pilling and, additionally, a higher color fastness.

Figure 16 and 17 show that the lower hairiness in the air-jet yarn results in less pilling in the subsequent and final end product.

ICI Pilling of Ring and Air-Jet Yarn Knitted Fabric Greige

100% Viscose, 1.3 and 1.45 dtex, 38 mm

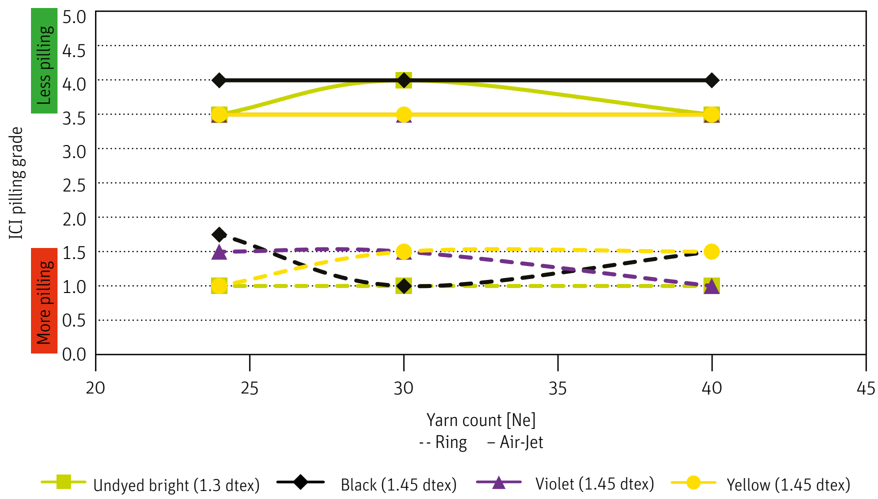


Source: TIS 26258/Technology & Process Analytics

Fig. 16: The subsequent knitted fabric shows considerably less pilling if produced with air-jet yarn.

ICI Pilling of Ring and Air-Jet Yarn Knitted Fabric Finished

100% Viscose, 1.3 and 1.45 dtex, 38 mm



Source: TIS 26258/Technology & Process Analytics

Fig. 17: The same results as in Fig. 16 are confirmed with the finished end product.

7.3. Washing Test

The hairiness in the yarn is also a major criterion for the abrasion resistance during the washing process. The hairiness in the yarn forms pilling on the surface of fabrics after certain washing cycles. The unique advantage of air-jet yarn is less hairiness. The pictures below show, that the air-jet yarn knitted fabrics exhibit no pilling on the surface – even after 20 washing cycles. The ring yarn knitted fabrics forms pilling already after 10 washing cycles.

Knitted Fabrics from Ring and Air-Jet Yarn after Certain Washing Cycles

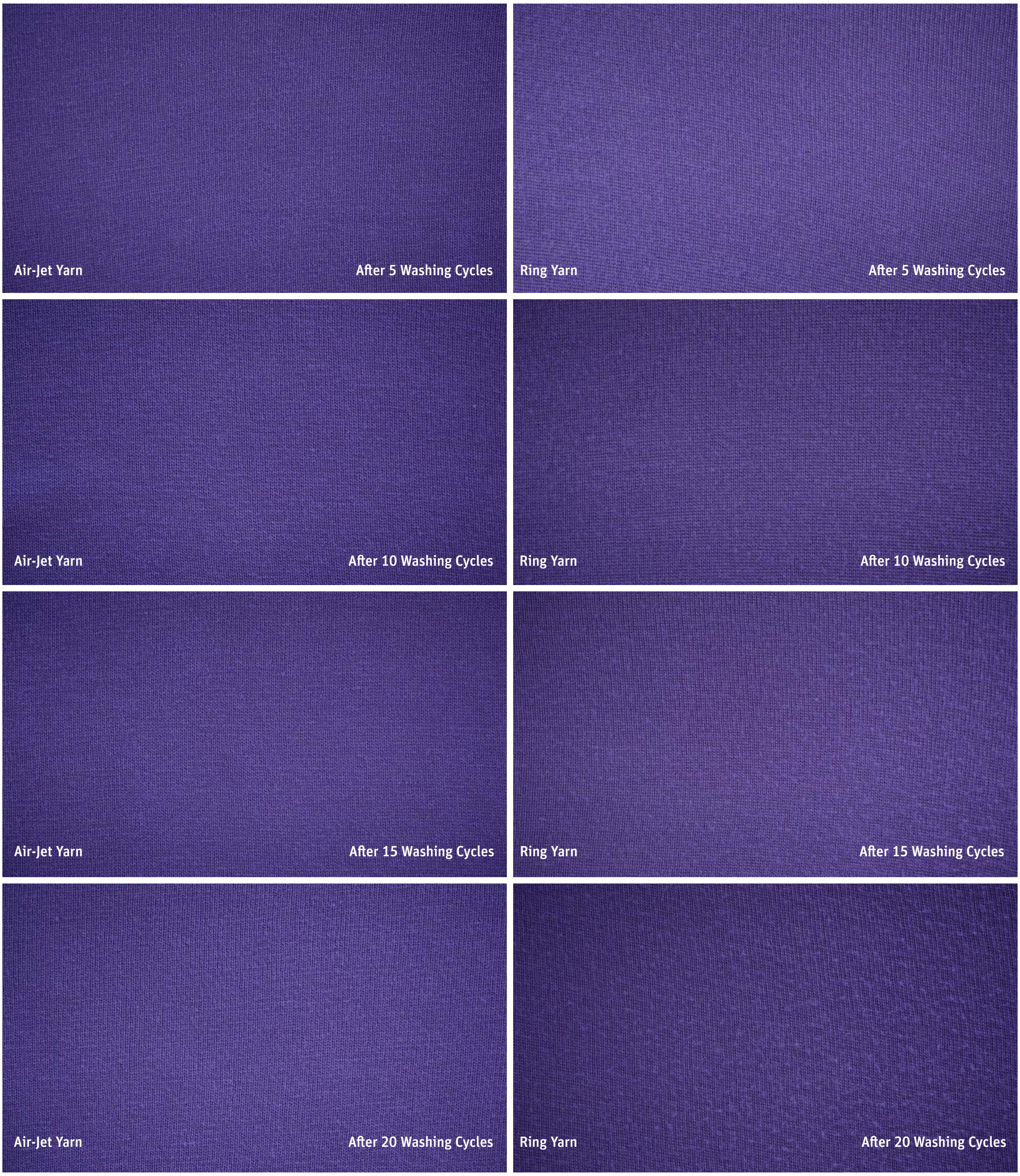


Fig. 18: The air-jet yarn knitted fabrics stand apart for their extreme durability.

Source: TIS 26258/Technology & Process Analytics

8. Higher Efficiency and Less Pollution

The yarn manufacturing costs that depend on the yarn count are between 20 – 25% lower with air-jet spinning than with the ring spinning technology, due to the higher productivity. The finer the yarn, the higher the possible savings with air-jet spinning in the respective yarn count range (Fig. 19).

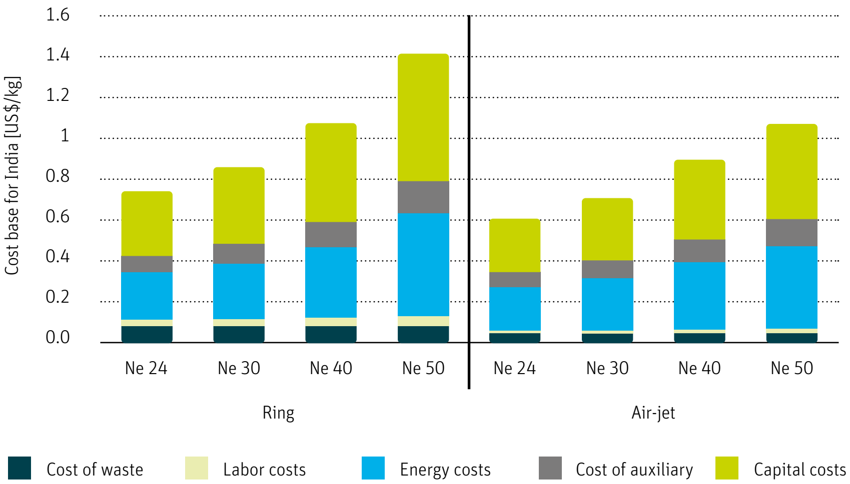
The dyeing of the textile fabric such as knits or wovens is an expensive process and the estimated cost is approximately 1 US Dollar per kilogram. Subsequently applied chemicals for dyeing the textile fabrics increase the price of the process and also pollute the environment by a higher water and energy consumption.

The direct addition of color pigments into the spinning solution during fiber manufacture is more cost-effective and more environmentally friendly. Spun-dyed fibers can already save up to 50% coloring agents depending on the color compared to the process of coloring the fabric.

The production costs per kg of yarn thus are below those of the conventional dyeing process of textile fabrics.

The potential for the future use of spun-dyed viscose is calculated to be 20% of the entire man-made cellulose market. This includes 100% spun-dyed fibers and blends such as mélange.

Comparison of Costs for Ring and Air-Jet Yarn
100% Viscose, 1.4 dtex, 38 mm



Source: TIS 26258/Technology & Process Analytics

Fig. 19: The cost saving potential increases with the production of finer yarns.

9. Summary

Birla Spunshades™ Fiber from Grasim Industries Limited and the Rieter air-jet spinning process of the latest J 26 machine generation enable the production of spun-dyed staple fiber yarns in optimal quality and at lowest yarn manufacturing costs.

As the color pigments are already part of the raw material and are equally distributed in the spin emulsion, spun-dyed viscose fibers provide certain benefits. However, the machine settings have to be adjusted according to the color of the fibers. This has to be taken into account mainly with the black fibers which exhibit the highest fiber-to-fiber friction.

The ring spinning system applies higher fiber-metal friction at the technology components compared to air-jet spinning, and, as a result, more fibers along the yarn strand axis are pushed up. The fiber stress with air-jet spinning is lower.

Concerning the characteristics of the spun-dyed viscose yarns, the evenness and tenacity of ring yarn is higher than that of air-jet yarn. However, this measured yarn evenness of air-jet yarns does not give the full picture of what the fabric will look like.

This is mainly due to the special yarn structure of the air-jet yarn which results from the bigger yarn diameter, the twisted fibers around the core fibers, and the lower hairiness.

The examination of the woven fabrics shows that processing spun-dyed viscose on an air-jet spinning system results in a better optical evenness than with ring spinning. One reason for that is the lower fiber stress with air-jet spinning.

When looking at the fabrics, another interesting finding is that processing spun-dyed viscose on an air-jet spinning system also results in a better evenness compared to processing raw white fibers. As a conclusion, the combination of spun-dyed fibers and air-jet spinning creates new benefits.

Further findings for processing spun-dyed viscose on an air-jet system are:

- **Highest efficiency**
  due to lower yarn manufacturing costs by means of the air-jet spinning technology combined with lower total production costs achieved by the dyeing process of spun-dyed fibers
- **Reduced environmental impact**
  thanks to the use of less environmentally hazardous chemicals for the dyeing process
- **Higher quality for the end user**
  due to more intense colors of viscose compared to cotton
- **Higher color fastness and color intensity**
  with spun-dyed fibers compared to the dyeing of the finished fabric structure
- **Higher washing resistance**
  due to less hairiness in the air-jet yarn and less pilling on the surface of the fabrics after certain washing cycles
- **Better optical evenness**
  because of lower fiber stress with air-jet spinning in combination with spun-dyed fibers compared to the ring spinning process

10. Notes

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

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

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

www.rieter.com

3358-v1 en 2009