Polyester – Lyocell Blend on Air-Jet Spinning for Weaving Application
## Content

1. Potential for Air-Jet Spinning Technology ........................................... 3
2. Application Areas of different End Spinning Technologies ................. 4
3. Trial Conditions .................................................................................. 5
3.1. Raw Material ................................................................................ 5
3.2. Technology Components and Machine Settings ......................... 6
4. Fiber Preparation Results .................................................................. 9
5. Further Improvement in Yarn Structure ............................................ 11
6. Yarn Quality over the Blend Ratio Polyester and Lyocell ............... 13
7. Influence of Plyed Air-Jet Yarn .......................................................... 22
7.1. Two-Ply Yarn Quality .................................................................. 23
8. Fabric Quality .................................................................................. 30
8.1. Fabric Quality Greige .................................................................. 32
8.2. Fabric Quality Finished ................................................................ 34
9. Economy .......................................................................................... 37
10. Summary ......................................................................................... 38
10.1. Single Yarn ................................................................................ 38
10.2. Two-Ply Yarn ............................................................................ 38
10.3. Weaving and Fabric .................................................................... 38
10.4. Economy .................................................................................... 38
1. Potential for Air-Jet Spinning Technology

During the market launch of air-jet spinning, the range of possible application became increasingly established as new findings constantly emerged. Nevertheless, the technological market potential has not been achieved by far. The technical innovations and modifications on the machine make an increasing rise in operational reliability with various raw materials and yarn finenesses.

If a staple yarn production with 45 million tons per year and an air-jet yarn production potential of 10%, an average yarn fineness of 15 tex (Ne 40) and an average delivery speed of 420 m/min is presumed, then today an absolute air-jet spinning unit number of approx. 1.8 million resp. 38 million spindle equivalents can be considered as technologically realistic. Worldwide, up to 2016, only 0.29 million air-jet spinning units, that is 5.8 million spindle equivalents, were installed. (Fig. 1 + 2) In this respect, a multiple increase could be expected in the next few years compared to the current air-jet capacities. As the global consumption of staple fiber yarn also continues to increase, the air-jet spin unit potential will also additionally increase.

The time period up to the full exploitation of the technical potential is hard to assess. Experience with compact spinning has shown that a period of up to 15 years can certainly be considered as realistic until full utilization in the textile industry is achieved.
2. Application Areas of different End Spinning Technologies

In practice, the application range for air-jet yarns continually expands and is accelerated by constant machine development. This makes it possible to go even closer to raw material and yarn fineness limits.

If we examine the various end spinning processes, taking into account the respective raw materials, the very high flexibility in favor of the ring spinning technology is here apparent. In this connection, the use of natural fibers or fibers from natural polymers provides a very wide spectrum.

As well as the high flexibility of ring spinning to process different raw materials and yarn counts, the flexibility to produce special structures, effects and multi-component yarns should also be mentioned such as:
- twin yarns (twin and compact twin yarn = spin-twisted)
- fancy yarns
- core yarns

In contrast, the processing of 100% synthetic fibers such as 100% polyester has certain limitations with compact and air-jet spinning. (Fig. 3)

The respective advantages of the different yarn structures are reflected in the yarn application (Fig. 4). So, for instance, more than 60% of air-jet yarns are used in knitting.
The air-jet spinning technology has so far been primarily used in the range of knitting, because of the unsurpassable pilling performance. The demand to use air-jet yarn in weaving is increasing. To further explore the limits, the question of highly stable, air-spun yarns for weaving arises, that not only can be excellently processed in weft but also in warp when using an innovative raw material blend.

Hence, this analysis deals with the production of fabric from air-jet yarns with a simultaneous comparison to a ring yarn, so as to better assess and evaluate the values achieved.

3.1. Raw Material

For this reason, a polyester/lyocell blend was selected as the raw material (Fig. 5), which should give an optical wool characteristic for the application area of suiting or coat materials.

The following objectives were therefore pursued:

- To use fiber with highest strength, to reach the highest yarn strength for best running condition in the weaving process using the air-jet yarn in warp and weft.
- To see the impact of air-jet two-ply yarn.
- To find out if there is the same wool characteristic using polyester/lyocell blend instead of polyester/viscose blend.
- To find out if the wool characteristic effect is dependent on the blend ratio.

### TENCEL® Lenzing (CLY)

<table>
<thead>
<tr>
<th>Bright</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Fiber fineness:</td>
<td>1.3 d tex</td>
</tr>
<tr>
<td>Cut length:</td>
<td>38 mm</td>
</tr>
<tr>
<td>Strength:</td>
<td>41 cN/tex</td>
</tr>
<tr>
<td>Elongation:</td>
<td>13%</td>
</tr>
</tbody>
</table>

### TIFICO Polyester (PES)

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Fiber fineness:</td>
<td>1.37 d tex</td>
</tr>
<tr>
<td>Cut length:</td>
<td>38 mm</td>
</tr>
<tr>
<td>Strength:</td>
<td>57 cN/tex</td>
</tr>
<tr>
<td>Elongation:</td>
<td>21%</td>
</tr>
</tbody>
</table>

Fig. 5 – Raw material  
Source: Lenzing, TIFICO
3.2. Technology Components and Machine Settings

Different components and setting options on the air-jet spinning machine J 26 (Fig. 6) support a wide application range of raw material types and yarn counts.

So, for example, the technologically important parameters depending on raw material, fiber length and yarn count can be selected, such as the distance from the spinning tip to the gripping point of the delivery cylinder. (Fig. 7)

<table>
<thead>
<tr>
<th>Nozzle and distance</th>
<th>Raw material</th>
<th>Yarn count range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Z – 2 = 18.6 mm</td>
<td>Cotton</td>
<td>Ne 20 - 50</td>
</tr>
<tr>
<td>Z – 1 = 19.6 mm</td>
<td>PES/CO, CV, CLY, Modal</td>
<td>Ne 20 - 80</td>
</tr>
<tr>
<td>Z + 1 = 21.6 mm</td>
<td>PES, CV, CLY, PES / CLY</td>
<td>Ne 25 - 60</td>
</tr>
</tbody>
</table>
The machine setting for all raw material blends has been selected as follows:
(Fig. 8)

<table>
<thead>
<tr>
<th>Setting and components</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Sliver weight [tex]</td>
<td>2700</td>
</tr>
<tr>
<td>Total draft [-fold]</td>
<td>185.9</td>
</tr>
<tr>
<td>Delivery speed [m/min]</td>
<td>380.0</td>
</tr>
<tr>
<td>Spinning air pressure [bar]</td>
<td>6</td>
</tr>
<tr>
<td>FFE [type]</td>
<td>Z + 1</td>
</tr>
<tr>
<td>Spinning tip [type / Ø mm]</td>
<td>U 1.0mm</td>
</tr>
<tr>
<td>Distance FFE - twist element [mm]</td>
<td>1.3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Setting and components</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Spinning draft [-fold]</td>
<td>1.0</td>
</tr>
<tr>
<td>Pre draft [-fold]</td>
<td>1.78</td>
</tr>
<tr>
<td>Intermediate draft [-fold]</td>
<td>2.31</td>
</tr>
<tr>
<td>Break draft [-fold]</td>
<td>4.10</td>
</tr>
<tr>
<td>Main draft [-fold]</td>
<td>45.35</td>
</tr>
<tr>
<td>Top roller Middle/Infeed [type / mm]</td>
<td>R 174 / 30.0</td>
</tr>
<tr>
<td>Top roller Delivery [type / Ø mm]</td>
<td>R 170 / 29.5</td>
</tr>
<tr>
<td>Apron top roller [type / Ømm]</td>
<td>Steel roller / 27.8</td>
</tr>
<tr>
<td>Top apron [type / Ømm]</td>
<td>Yamauchi / TA-J 2/39.2</td>
</tr>
<tr>
<td>Bottom apron [type / Ømm]</td>
<td>Yamauchi / TA-J 2/39.2</td>
</tr>
<tr>
<td>Spacer pin [mm / colour]</td>
<td>3.5 brown</td>
</tr>
<tr>
<td>Infeed condenser [mm / colour]</td>
<td>8.0 x 2.5mm / red</td>
</tr>
<tr>
<td>Condenser VF [mm / colour]</td>
<td>4.5 x 1.2mm / red</td>
</tr>
<tr>
<td>Condenser ZF [mm / colour]</td>
<td>10.0 x 2.5mm / blue</td>
</tr>
<tr>
<td>Cylinder distance top roller [mm]</td>
<td>48-46-49</td>
</tr>
<tr>
<td>Cylinder distance bottom roller [mm]</td>
<td>48-45-47</td>
</tr>
</tbody>
</table>

Fig. 8 - Machine setting | 26
Source: TIS 27284 / Technology Process Analytics
To be able to obtain the optimal spinning conditions in terms of yarn quality and running properties, various technology components are available. (Fig. 9)
4. Fiber Preparation Results

The polyester/lyocell blend was manufactured in five different blend ratios by means of the draw frame blend. (Fig. 10) The yarn was spun with the air-jet and also with the ring spinning technology. The ring yarn gives the opportunity to compare the values achieved. Thus, with all blend variations, alongside the set objectives a direct comparison of air-jet to ring is possible to allow a better evaluation of the results achieved.
The nep content in the sliver for the air-jet spinning process does not significantly differ after the last drafting passage between the different blend ratios of polyester and lyocell. With all blend ratios, it lies in the range of 4 - 6 neps/gram fiber material. (Fig. 11)

Conversely, with the ring spinning process a higher number of neps (10 neps/gram fiber material) at the last drafting passage was established in comparison to the air-jet spinning process. The cause is the higher fiber mass of 30 g/m in the drafting unit with the ring spinning process compared to 17.5 g/m in the last drafting passage with the air-jet spinning process. (Fig. 12)

With the fiber preparation for both air-jet spinning and ring spinning, it is apparent on the mixing draw frame that with a higher polyester ratio, the nep content increases.

The results clearly show that the sliver feed quality is considerably influenced by the fiber mass in the drafting unit and by the raw material.

To what extent a higher nep content of a respective raw material component is reproduced over the following process stages depends on the fiber mass in the drafting unit, the settings on the draw frame and the number of drafting passages.

---

**Nep Content over Process Stages - AFIS**
Polyester/lyocell, 1.3 dtex, 38 mm, air-jet process

**Nep Content over Process Stages - AFIS**
Polyester/lyocell, 1.3 dtex, 38 mm, ring process
5. Further Improvement in Yarn Structure

The yarn tenacity decreases with the increase in delivery speed because of the wrapping fiber angle which becomes more flat. (Fig. 13) The yarn structure could, however, be significantly improved by injection of fluid in the yarn formation process. Using injection has a significantly positive influence on the fiber integration in the yarn bundle. The density of the yarn increases which results in a higher fiber-fiber friction and therefore more strength. So the injection system increases the yarn tenacity up to 2.5 cN/tex, depending on the blend proportion.

The higher the polyester content and delivery speed of the air-jet spinning machine, the greater is the positive influence of the injection.

Depending on the polyester content, by using injection the delivery speed resp. the production can be increased by approx. 10% while maintaining the yarn strength.

Not only is the yarn strength positively influenced by injection, but also the elongation increases slightly due to injection by absolute 0.2%. (Fig. 14)

Consequently, using fluid injection must also positively affect the winding and abrasion resistance of the yarn with polyester or polyester-rich blends.
The yarn structure shows that the angle of the wrapping fiber increases with injection. (Fig. 15)

This creates more pressure on the parallel core fibers and results in a higher fiber-fiber friction and so more density and yarn strength. It means the effect of losing yarn strength with higher delivery speed can be partially compensated by injection.

The cause of the positive effect can therefore be explained, that the fluid is immediately spread over the fiber surface with both polyester and viscose fibers. With cotton fibers as well as with “dewaxed” cotton fibers, the fluid initially remains as drops. The moistening of the fiber surface is therefore worse than with polyester or viscose. (Fig. 16)

Whether and how far the moisture is absorbed is not decisive for the fiber bonding. As far as a good moistening of the fiber surfaces is concerned, this has a positive effect on the fiber bonding where a higher bending rigidity of the fibers, as with polyester, is the case. That means the wrapping fiber angle becomes steeper. A better fiber bonding affects the following yarn values in a positive way:

- mean tenacity
- tenacity weakpoints
- hairiness
- winding and abrasion resistance

The following air-jet yarns in this study are all produced with injection.

**Polyester / Lyocell, 1.3 dtex, 38mm, Ne 40**

<table>
<thead>
<tr>
<th></th>
<th>100% CO</th>
<th>100% CO (without Wax*)</th>
<th>100% CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>50% PES / 50% CLY</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>With injection</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Without injection</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>50/50% PES/CO</th>
<th>65/35% PES/CO</th>
<th>100% PES</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>without Wax: CO Wax removed with Acetone</em></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Source: TIS 27284 / Technology Process Analytics*
6. Yarn Quality over the Blend Ratio Polyester and Lyocell

The ring yarn exhibits less unevenness than the air-jet yarn. (Fig. 17) From previous studies we could already learn that in such a comparison between different yarn structures, the source of any differences are not faults but mainly the individual yarn structures themselves. That is also the reason why there is no correlation between the unevenness values measured in the yarn on different yarn structures and the optical evenness in the fabric. The correlation between yarn and fabric unevenness is only given by using the same yarn structure.

Far more important for any process optimization is the awareness that unevenness increases with a higher polyester ratio in air-jet and ring yarn. This can be seen even in thin and thick places. (Fig. 18/19)

Thin and thick places are the main influencing parameter for unevenness. The reason is that with a more than 50% polyester ratio, the drafting force increases. Higher drafting force in a drafting unit is always a risk for uneven drafting work and therefore greater unevenness.

For such a study, the machine setting must kept constant as otherwise the influence of the blend ratio cannot be seen and any changes of settings before would be a speculation and a risk.

Due to the winding process, the unevenness with ring yarn increases generally, depending on the raw material and winding conditions. In that case and due to optimal friction points on the winding machine, there is only an increase of relatively less than 5% with ring yarn which is a normal value.
The rise in thin places with increasing polyester content is the same on air-jet and ring when calculating in percentage.

The fine neps continually decrease with increasing polyester content in both air-jet and ring yarn (Fig. 20). In this respect, the decrease of these fine neps cannot be traced to the behavior of an individual end spinning process. The causes here are found in the greater fiber bending rigidity of polyester compared to that of lyocell. This means that the polyester has a lower tendency to nep formation due to the higher fiber bending rigidity. However, with the air-jet yarn structure, the stability of the fiber bonding deteriorates. The fiber bonding in the yarn body can be verified with the “yarn windup test” (Fig. 22).

The clear rise in fiber neps in the ring yarn due to the winding process shows that the neps in the ring yarn must have further causes than with air-jet yarn. On the ring yarn, fiber neps are formed primarily by fiber sloughing on the “ring traveler system” or by the rewinding process. This means that when considered in terms of the nep size/nep class (140% or 200%), the differences in absolute figures between air-jet and ring yarn must be contrary.
In the coarse neps (Fig. 21) the air-jet yarn indeed shows fewer neps than the ring yarn. The coarse neps in the 200% classes have a lower mass increase with the periodically distributed wrapped fibers along the yarn axis than the sloughing neps on ring yarn.

In other words, with the ring yarn structure, the fiber neps which can primarily be formed by fiber sloughs are greater in their mass than the mass variants which are created by the yarn structure with air-jet yarn.

Thus, the number of coarse neps is higher with ring yarns than with air-jet yarns. Consequently, more coarse neps must also be visible in ring yarn fabric than with air-jet fabric.

The following image (Fig. 22) shows a yarn roll tester developed by Rieter technology department. This measuring method serves to determine the fiber bonding tendency in the yarn body. The respective fibers are stretched in a carriage and rolled as long from left to right on a defined fabric as the fiber breaks.
Based on the previous positive results gained by an injection in the yarn formation process, it was recognized that the stability of the fiber bonding must be strongly dependent on the fiber bending rigidity of the different raw materials. Therefore, the fiber bonding in the yarn body was more closely examined with different raw materials such as cotton, viscose and polyester. (Fig. 23/24/25)

From the raw materials tested, the highest number of motion cycles was reached with cotton until the fiber broke. With viscose, fewer cycles were reached than with cotton.

As the measurement showed, the winding resistance when using polyester exhibited the smallest number of motion cycles. The lower “bonding stability” in the yarn package with polyester fibers is due to the fiber bending rigidity.

The bending rigidity of the fibers thus influences the bonding-friendliness of the fibers in the fiber package. Bend-rigid fibers consequently also inevitably reduce the yarn spinning limit. Fibers with higher bending rigidity thus provide greater resistance to the twist insertion.

The bending rigidity of the fibers is made up of the elasticity module of the respective raw material and the moment of inertia (fiber cross-section and fiber profile).

If the fiber characteristics are applied to the yarns and the textile end product, the advantage of a lower creasing tendency occurs with a higher bending rigidity when processing polyester fibers.
The rolling resistance of the yarns is therefore not to be confused with the yarn tenacity. The test shows that because of the lower rolling resistance, the fiber bonding with polyester fibers in the air-jet spinning process is of major significance for the yarn formation process and the piecing quality. In addition, from this it can be derived that with polyester the fiber bonding in the yarn body to avoid yarn thick places is of great importance.

The measuring results were, according to the raw material, strongly influenced by the delivery speed on the air-jet machine and the yarn tension on the test device. As long as the yarns in the woven or knitted fabric do not have a possibility to be wound by mechanical forces, no disadvantages in the finished textile product also oppose this criterion. The results show, however, that by a suitable injection in the fiber sun with air-jet spinning, a decisive step is achieved in significantly improving the yarn formation process when processing polyester fibers.

Due to the higher fiber-fiber friction in the yarn package the mean tenacity with ring yarns, depending on raw material blend, lies around 12 – 20% higher than with air-jet yarns. The fiber substance yield with ring yarns from the winder amounts to approx. 62% and with air-jet yarns approx. 52%.

With both end spinning systems, the mean yarn tenacity rises steadily with an increasing proportion of polyester as a result of the polyester’s higher fiber tenacity. (Fig. 26)
It can be assumed that with ring yarns, a mean yarn tenacity of 16 cN/tex satisfactorily fulfills the requirements of the weaving running properties. With air-jet yarns, however, the mean yarn tenacity should be higher in order to keep the yarn weak places in a range which prevents ends down in weaving.

Generally, it can be stated that the higher the mean yarn tenacity, the smaller the risk that the respective yarn weak places will lead to an ends down. This statement can be justified by the fact that with the rise of the “mean tenacity”, normally also the yarn weak places move out of the critical range where high thread tension on the fiber leads to a break.

A key criterion for an adequate load bearing capacity in weaving is the warp. The warp yarn must be able to withstand the various stresses in the weaving process by means of sufficient tenacity and elongation, meaning by the yarn processability.

In this respect, the yarn weak places and the variation of the yarn tenacity play an equally decisive role. (Fig. 27) The yarn weak place should not lie below 100 cN and 2.5% elongation for warp and weft in the weaving application.

On the basis of air-jet yarn, a yarn count of Ne 40 (approx. 15 tex) and a blend of 20% polyester with 80% lyocell, a break force of up to 240 cN is still calculated at a declared value for weak places of 0.1%. The risk for a thread break is therefore small. Even at 0.05% of the measured values, the break force still lies at 220 cN.
It is well known that a connection also exists between the break force variation and the ends down in weaving. To more closely observe the evaluation of yarn tenacity variation, the explanation should be given that the variation of the yarn tenacity with ring yarns, produced from cotton, should not lie above 9%. The requirement in this case relates, however, to lower mean yarn tenacity. In practice, it is often attempted to keep the number of yarn weak places low by means of a minimal variation of tenacity. A higher variation of the break force of 9% thus does not mean in every case a higher ends down rate. What is more important is whether the weak places lie outside the range leading to an ends down.

With the different blends, the tenacity variation increases with a higher polyester ratio, i.e. increasing fiber tenacity and therefore increasing “mean yarn tenacity”, with both yarn structures. (Fig. 28). That means, the tenacity variation rises with a simultaneous increase of the mean yarn tenacity due to the change in raw material. With a high proportion of polyester, variation with air-jet yarn is approx. 11.5% and with ring yarn approx. 10.5%.

In the distribution diagram of the “Tenacity/Elongation”, a diagram accordingly emerges where an increasing polyester ratio primarily shows only a slimmer and longer drawn-out (ring yarn) area resp. a thicker and upward-shifting (air-jet yarn) area. (Fig. 29/30)
The yarn weak points with air-jet yarns therefore only move very slowly out of the “danger zone” as a result of changing a raw material component. The variation of yarn tenacity as well as the “mean yarn tenacity” show that the weak places in the yarn can only be partially reduced by means of the raw material composition. An essential benefit is therefore offered by injection, to keep the number of weak places in the yarn low through better fiber bonding. The number of weak places in this particular application marginally differs from that of a ring yarn.

In particular with the air-jet yarn structure, it should be attempted to optimize resp. ensure the number of undesired weak places and variation of the tenacity across the yarn formation process.

Alongside the fiber elongation, meaning the respective raw material, the yarn elongation is influenced by the yarn structure (fiber substance yield) and the level of yarn twist. (Fig. 31) Depending on the raw material and the yarn twist on ring yarn, a higher elongation results in favor of ring yarn than with air-jet yarn. With an increasing proportion of polyester, the yarn elongation on ring yarn rises due to the higher fiber substance yield in contrast to air-jet yarn by an absolute figure of approx. 1%. Here, the ring yarn elongation shows an absolute figure of up to 1.8% higher than the air-jet yarn.

The high processability on both ring and air-jet yarn structures would very well fulfill the weaving requirements by means of the high yarn tenacity and elongation, even with the processing of single yarns. With a processability of air-jet yarns, which reaches 900 [cN cm] from tenacity and elongation, no problems are
expected with high-performance weaving. As benchmark for the warp and weft processing, approx. 500 [cN cm] can be estimated for the required processability of the high-performance weaving machines.

With an increasing proportion of polyester, the hairiness with ring yarn becomes slightly reduced. (Fig. 32) Polyester fibers cause fewer fiber spreads than lyocell fibers at the spinning triangle following the delivery roller pair of the ring spinning machine drafting unit. The rewinding process of ring yarn shows a far greater influence on hairiness than the polyester ratio. The hairiness with ring yarn significantly increases by approx. 23 – 24% due to the rewinding process.

With air-jet yarn, the two raw material components have no influence on the hairiness in total. The hairiness is only influenced by the yarn structure. The air-jet yarn has, as was expected in this case, a clearly lower hairiness compared to ring cops (approx. 13 – 28%) and ring package (approx. 30 – 40%).

As also with the total hairiness, the longer hairs of > 3 mm become slightly fewer with an increasing polyester ratio in ring yarns. (Fig. 33)

The rewinding process from cops to package has a clearly negative influence on the hairiness. With air-jet yarn, no hairiness of the longer fibers of > 3 mm can be detected.
7. Influence of Plyed Air-Jet Yarn

Conventional ply yarns such as ring yarn have the following objectives:
- increase strength
- better running conditions in the downstream process
- better evenness
- high washing resistance
- low pilling
- soft drape
- higher form stability

Depending on the type of manufacture, a distinction is made between two-ply and multiple ply yarns.

As in the case of yarns, the direction of twist is described by the letters S and Z. (Fig. 34)

The direction of twist of the ply yarn is usually opposite to that of the standard spun yarns.

The twist is described as loose, normal or hard, depending on the number of twists per unit of length.

The decision to use a two-ply yarn for air-jet and ring was made due to the application for suits or classical jackets.

The yarn structure of the single yarns for ring and air-jet as well as the yarns processed to twisted yarn is visible from the microscopic images. (Fig. 35) Here, the typical, far lower hairiness and the special structure of the fiber loops of air-jet single yarn compared to ring yarn can be easily recognized.

After the twisting process, the differences between ring and air-jet yarn are only recognizable on closer inspection.

![Fig. 34 - Principle of ply yarn](Source: Rieter)

![Fig. 35 - Yarn structure](Source: Technology Process Analytics)
7.1. Two-Ply Yarn Quality

Usually, the twist of the two-ply ring yarns is around 20 to 30% less than the spinning twist and is contrary to the twist direction with end spinning.

To determine the optimal twist for the two-ply air-jet yarn, the yarn characteristics were determined not only with a different twist direction but also with a different twist coefficient.

The greater the twist coefficient, the greater the twist contraction. Through the twist contraction, the yarn length is shortened and the yarn weight per length unit rises. In the case of an S-twist direction, the yarn coarsening resp. twist contraction amounts to 3 to 9% according to the twist coefficient. With a Z-twist direction, yarn coarsening due to the twist contraction amounts to 10 to 15%. (Fig. 36)

The twist contraction and therefore the fiber stress in the yarn are considerably higher with the Z-twist direction than with the S-twist direction. The higher stress on the fibers in the same twist direction with spinning as also with twisting (in that case, in the Z-direction) leads to excessive torsional loads in the yarn, which is obvious in a too high curling tendency of the twisted yarn.

Through the doubling of two yarns, as takes place in twisting, the yarn evenness improves by approx. 25 – 30%. (Fig. 37) The unevenness can be theoretically determined by the mass increase from Ne 40 to Ne 20 after the “doubling principle”.

\[
CVm_{\text{twisted yarn}} = \frac{CVmE}{\sqrt{\text{Number of doublings}}}
\]

whereby

\[
CVmE = \text{unevenness on single yarn}
\]

According to the theoretical connection between evenness and the distribution of the tenacity through the doubling, an unevenness of 10.3 CVm would accordingly be calculated. The following results show that the unevenness is not only dependent on the single yarn and the number of doublings, but also on the twist direction and the twist coefficient $ae$.

Hence applies:

\[
CVm_{\text{twisted yarn}} = \frac{CVmE \times F}{\sqrt{\text{Number of doublings}}} - (a \times ae)
\]

whereby

- Factor “F” with twist direction opposite to spinning direction = 1.19
- Factor “F” with twist direction same as spinning direction = 0.96
- Increase variable “a” with both twist directions = 0.35
- Twist coefficient English = $ae$
By applying the Z-twist direction, an improved unevenness, thin places and thick places was achieved compared to the S-twist direction. However, here the yarn exhibited a strong curling tendency. Additionally, it must be expected that the fiber stress is also too high. The question, whether the fibers and therefore the yarn are damaged by this will show up in the tenacity and elongation.

The thin places in the twisted yarn compared to single yarn have become massively improved to such an extent that a change from -40 to -30% to a more sensitive fault class was made.

As was already recognizable with the unevenness, the thin places (Fig. 38) and thick places (Fig. 39) with the Z-twist direction are considerably better than with the S-twist direction. Presumably the small irregularities are better “concealed” by the massive twist contraction (Z) than with a more expedient twist contraction (S).
The nepss (Fig. 40) also decline with increasing twist coefficient with S-twist. The twist contraction thereby conceals not only fine structural differences in the yarn but also fine fiber nepss. With the Z-twist direction, the yarn is already so strongly twisted that even the influence exerted by the twist coefficient no longer has any effect on the yarn structure and any possible fine fiber nepss. The suspicion of a too high fiber stress when using the same twist direction as the spinning direction, in other words the Z-direction, is confirmed.

The opposing S-twist direction to the Z-spinning direction clearly gave the highest tenacity values and thus lower stress on the air-jet yarn. It was already suspected with the curling tendency that the torsion forces in the twisted yarn were too high.

To keep the curling tendency as low as possible, the twist direction in this twist range – even with air-jet yarns – must be selected opposite to the spinning direction.
The smaller the yarn twist coefficient the smaller the influence of the twist direction on the tenacity. It clearly shows that already with a relatively small yarn twist, the greatest increase in tenacity takes place compared to single yarn. (Fig. 41)

The yarn twist should therefore be in the “opposite spinning direction” and be kept relatively low. The optimum for the gain in tenacity and thus for the lowest fiber stress can be expected at a value of $\alpha_e 3.3$.

In this respect, the same rule applies with air-jet yarn as with ring yarns. The twist in the yarn should counter the twist direction of the spinning process to avoid high torsional forces (loss of tenacity and curling tendency) in the twisted yarn.

Use of far lower twist coefficients than $\alpha_e 3.3$ in combination with the same twisted yarn and also spinning direction can offer the potential, according to the basic conditions, to make the twisting process more productive. (Fig. 42) However, in the case of such a possibility, it must be observed that the tenacity of the air-jet single yarn is already optimally designed.

Where the spinning and twist direction was the same, further clarifications with a polyester/lyocell blend of 50/50 determined a twist coefficient of $\alpha_e 2.2$. The measuring series clearly showed that the influence on the tenacity gain exerted by the twisted yarn process is greater than the influence exerted by the polyester ratio.
An overtwist in the air-jet yarn had an equally negative effect on the weak places. The weakest yarn places lose tenacity as soon as the stress on the fibers in the yarn package exceeds a certain torsional force. (Fig. 43)

With the S-twist on the yarn, the weakest points could be increased up to a twist coefficient of ae 4.6 in the “weak points tenacity”, however at the expense of the “mean tenacity”. In this respect, it is recommended not to twist with a higher twist coefficient than ae 3.3.

The same twist direction as the spinning direction, that is Z-direction, and the comparison with the single yarn show clearly that the twist factor at > ae 3.3 is in every case overtwisted.

By doubling two yarns, as is done with yarn twisting, the variation of the tenacity improves with S-twisted yarn by approx. 38%. (Fig. 44) The tenacity variation becomes reduced with increasing yarn mass and can, as with the unevenness, be theoretically determined according to the “doubling principle”.

Accordingly, a variation of the tenacity of 8% CVF was calculated.

\[
CVF \text{ twisted yarn} = \frac{CVFE}{\sqrt{\text{Number of doublings}}}
\]

whereby

\[
CVFE = \text{variation of the tenacity on single yarn}
\]

As also with the unevenness, it became apparent that the actual variation of tenacity is also dependent on the twist direction, but not or hardly from the twist coefficient.

\[
CVF \text{ twisted yarn} = \frac{CVFE \cdot F}{\sqrt{\text{Number of doublings}}}
\]

whereby

- Factor twist direction
  - at twist direction opposite to spinning direction = 0.86
  - at twist direction same as spinning direction = 1.15
The elongation on the S-twisted yarn is massively better than on the single yarn, primarily due to the greater fiber mass of the yarn. (Fig. 45) The reason for the increase of yarn elongation with greater twist coefficient is found in the greater twist contraction resp. yarn length shortening, which is shown by the tensile load before the ends down across the greater change in direction for this. The same also applies, due to the higher twist contraction, when the direction for both twisting and spinning is the same.

The yarn hairiness (Fig. 46/47) on the S-twisted yarn is around 50 – 60% higher than with single yarn. With increasing yarn mass, the yarn hairiness is known to increase, as also with ring and rotor yarns. The reason is that the number of fibers in the cross-section resp. the yarn circumference is directly connected to the amount of the protruding fibers. With air-jet yarn with their relative low hairiness, this also increases with coarser yarn. However, due to the very low hairiness with air-jet yarns, the increase must be far less strong with the coarsening of the yarn mass.

The biggest difference in hairiness from single yarn Ne 40 to the yarn count on the twisted yarn of Ne 20 (Ne 40/2) can therefore not be explained entirely by the increase of the bulk resp. number of fibers in the yarn cross-section. A significant part of the hairiness increase must be traced back to the adverse rewinding process. As far as hairiness is concerned, the advantages and disadvantages of a twisting process with air-jet yarn must be very carefully assessed.
The negative influence of the twisting process in respect of hairiness is all the greater, the smaller the yarn twist resp. the smaller the torsion forces (e.g. twist direction) are on the fibers. With increasing twist coefficient with twisting, the yarn hairiness decreases.

As already seen, this is nevertheless related to the accordingly massive disadvantage of a loss in tenacity.

An “overtwist” of the yarn, as is with the Z-twist, can in fact bring the hairiness to the level of the single yarn or even below. However, this is at the expense of the tenacity and a too high curling tendency on the twisted yarn.

With the hairiness lengths of ≥ 3 mm, in all cases the hairiness was no longer measurable with twisted yarn.

![Hairiness vs Twist Factor on Air-Jet Yarn](image)

**Hairiness vs Twist Factor on Air-Jet Yarn**
67% polyester/33% lyocell, 1.3 dtex, 38 mm, Ne 40/2

![Fig. 46 - Two-plyed yarn quality](image)

Source: TIS 27284 / Technology Process Analytics

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**Hairiness vs Twist Factor on Air-Jet Yarn**
67% polyester/33% lyocell, 1.3 dtex, 38 mm, Ne 40/2

![Fig. 47 - Two-plyed yarn quality](image)

Source: TIS 27284 / Technology Process Analytics
8. Fabric Quality

For the fabric production, a yarn twist coefficient of \( a_e = 3.8 \) and a twist direction opposite to the spinning direction, that is “S”, was selected. According to the findings from the yarn results, however, a twist coefficient of \( a_e = 3.3 \) for the fabric production would have sufficed. (Fig. 48)

The running properties were faultless in the weaving preparation as well as in the weaving process. Operation was carried out without warp sizing. All weaving requirements were fulfilled. Spinning-related faults in the woven goods could not be identified in the scope of the trial. It can therefore be assumed that a first-class quality in the subsequent inspection can be achieved. As a guideline, 10 faults per 100 meter fabric will be accepted on inspection of the fabrics, although usually faults are distributed at a max. of 1/3 each between spinning, weaving and finishing.

Fabric finishing with the lyocell-rich blend was made with prior mercerisation and subsequent jigger dyeing. (Fig. 49) With the polyester-rich blends, a high-temperature jigger dyeing was carried out to avoid dyeing streakiness.

The appearance of the wool characteristic with the polyester/lyocell blend was achieved independently of the component ratios. (Fig. 50) The fabric design attained matches the typical applications of suiting materials or classical jackets as far as the optics are concerned. The fabric touch, however, is strongly dependent on the raw material and the yarn structure and thus results in a unique touch for new and further textile applications.

![Fabric finishing](Source: TIS 27284 / Technology Process Analytic)
<table>
<thead>
<tr>
<th></th>
<th>Ring 40/2, ae 3.8</th>
<th>Air-jet Ne 40/2, ae 3.8</th>
<th>Air-jet 40/2, ae 3.8</th>
<th>Air-jet 40/2, ae 3.8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fabric Type</td>
<td>67/33% PES / CLY</td>
<td>20/80% PES / CLY</td>
<td>67/33% PES / CLY</td>
<td>80/20% PES / CLY</td>
</tr>
<tr>
<td>Color</td>
<td>Polyester dyed</td>
<td>Lyocell dyed</td>
<td>Polyester dyed</td>
<td>Polyester dyed</td>
</tr>
</tbody>
</table>

Fig. 50 - Fabric finishing

Source: TIS 27284 / Technology Process Analytics
8.1. Fabric Quality Greige

The measurements on the woven fabric were carried out on fabric of 5 cm width in raw white and finished condition, in order to also learn some of the important criteria regarding the influence of finishing on the fabric.

With an increasing proportion of polyester up to 67%, the fabric breaking load in the weft and also in the warp direction significantly increases. Subsequently, through this fabric bonding, an increase of the breaking load due to an even higher polyester percentage no longer exists. (Fig. 51/52)

The fabric breaking load with ring yarns is around 11% higher in the weft direction and around 14% higher in the warp direction, due to the higher yarn tenacity of 20%.

This means that lower yarn tenacity on air-jet yarn compared to ring yarn due to the fabric bonding will not necessarily be noticeable to the same extent in the fabric breaking load. The reason is that part of the lower air-jet tenacity is compensated by the yarn bonding in the fabric, resulting from the friction forces in the fabric.

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**Breaking Load vs Blend Ratio on Air-Jet Yarn and Ring Yarn**

Polyester/lyocell, 1.3 dtex, 38 mm, Ne 40/2, woven fabric 2/1 twill, greige

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**Tenacity vs Blend Ratio on Air-Jet Yarn and Ring Yarn**

Polyester/lyocell, 1.3 dtex, 38 mm, Ne 40/2, woven fabric 2/1 twill, greige
The fabric elongation is an important criterion for the wearing comfort resp. the creasing tendency of suits or jackets. (Fig. 53)

It is well known that fabrics from man-made fiber, wool and silk exhibit better form stability than cotton. This is not least due to the higher fiber, yarn and thus also fabric elongation.

In the fabric weft direction, using air-jet yarn achieves the same elongation as when using ring yarn. On the contrary, measured in the warp direction air-jet yarn reaches a higher elongation than ring yarn and this despite the fact that the yarn elongation with air-jet single yarn is lower than with ring single yarn.

The plyed yarn twist in “S” direction with air-jet as well as with ring yarn was in both cases $\alpha = 3.8$.

On air-jet twisted yarn, a twist contraction of 5% was shown and with ring yarn only 3.5%.

The elongation on air-jet and twisted ring yarn was 12%.

In this respect, the higher fabric elongation in the fabric raw state in the weft direction with air-jet yarn can be explained by higher twist contraction.

Ultimately, the fabric characteristics after the finishing process are decisive and qualify the influences of the spinning and twisting processes.

In total, the working capacity of the fabric with the 67/33 blend, manufactured from air-jet yarn, is the same as with ring yarn. (Fig. 54)
8.2. Fabric Quality Finished

With the finishing of the textile fabric, many positive characteristics such as touch, drape and optics of the goods can be obtained. The finishing can, depending on raw material, unfortunately also negatively influence the breaking load resp. tenacity of the fabric. With an 80% lyocell proportion, the fabric tenacity can be approx. 10% lower due to the finishing process.

With an increasing or high polyester percentage, however, no disadvantages in the fabric tenacity are created by finishing. (Fig. 55/56)

In this connection, with fabric development using new yarn structures and according to the raw material used, consideration must be given to how the chemical finishing can be adapted and clarifications made.
The elongation (Fig. 57) in the fabric increases over the finishing process in the weft direction and decreases in the warp direction and therefore no clear behavior can be recognized during the finishing process.

The working capacity (Fig. 58) shows no clear influence exerted by the finishing process. The working capacity rises with an increasing polyester proportion. After the finishing process, the working capacity of the fabric manufactured from ring yarn is approx. 15% higher than that manufactured from air-jet yarn. The cause can be found in the higher yarn working capacity of twisted ring yarn.

### Elongation vs Blend Ratio on Air-Jet Yarn and Ring Yarn
Polyester/lyocell, 1.3 dtex, 38 mm, Ne 40/2, woven fabric 2/1 twill, finished

<table>
<thead>
<tr>
<th>Blend proportion [%]</th>
<th>Elongation [ % ]</th>
</tr>
</thead>
<tbody>
<tr>
<td>20% PES 80% CLY</td>
<td>14</td>
</tr>
<tr>
<td>67% PES 33% CLY</td>
<td>20</td>
</tr>
<tr>
<td>80% PES 20% CLY</td>
<td>26</td>
</tr>
</tbody>
</table>

Fig. 57 - Fabric quality finished

### Work Capacity vs Blend Ratio on Air-Jet Yarn and Ring Yarn
Polyester/lyocell, 1.3 dtex, 38 mm, Ne 40/2, woven fabric 2/1 twill, finished

<table>
<thead>
<tr>
<th>Blend proportion [%]</th>
<th>Work capacity [kN.mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>20% PES 80% CLY</td>
<td>5</td>
</tr>
<tr>
<td>67% PES 33% CLY</td>
<td>15</td>
</tr>
<tr>
<td>80% PES 20% CLY</td>
<td>35</td>
</tr>
</tbody>
</table>

Fig. 58 - Fabric quality finished
With the blend with a 67% polyester component, the pilling values (Fig. 59/60) give the same result with the twisted ring yarn as with air-jet yarn. Here, the massive influence of twisting on the pilling values is apparent. It can thus be seen that the positive influence of twisting on the pilling characteristics is greater than the influence of the different yarn structure of single yarns. The pilling values of air-jet yarn also show that this is not influenced by the blend composition.

The pilling values are therefore positively influenced in the following sequence:

1. twisting process
2. yarn structure
3. raw material
9. Economy

The yarn manufacturing costs were calculated for Indonesia (Fig. 61) and China (Fig. 62) based on the selected spinning schedule which was determined in the trial.

The manufacturing costs of air-jet yarns do not differ with the two countries Indonesia and China. Conversely, with ring yarns and the higher personnel intensity involved, the costs in China are minimally higher than in Indonesia.

The manufacturing costs of ring yarns are approx. 33% higher in Indonesia and 35% higher in China than that of air-jet yarns.

With an increasing proportion of polyester, the manufacturing costs decrease minimally.

One reason is the waste costs on the cards. These are with 100% polyester 0.6% and with 100% lyocell 1.5% calculated waste.

With air-jet yarn, the yarn manufacturing costs play a lesser role despite the lower waste costs with an increasing lyocell percentage. The reason is that with air-jet spinning, slightly higher investment costs for the injection equipment are calculated from a polyester ratio of 50%.
10. Summary

The analysis showed the influences and properties of yarn and fabric with polyester-lyocell blends in air-jet spinning for weaving applications.

10.1. Single Yarn

- Using the new injection technology, the yarn formation process is positively influenced. The tenacity, rolling resistance and abrasion resistance can thus be massively increased using polyester or polyester-rich blends.
- Weak places in the yarn can only be minimally changed by means of the raw material blending ratio. The primary aim must be to optimize across the yarn formation process any undesired tenacity weaknesses or variation values for tenacity and elongation.
- The measured unevenness of air-jet yarns is higher compared to ring yarns. With an increasing proportion of polyester, the unevenness independent of yarn structure increases. The unevenness values include the influence of the yarn structure and can therefore not be comparably evaluated in absolute terms.
- The yarn neps gradually reduce with an increasing proportion of polyester in both yarn structures. If the measuring range for air-jet yarn applies to the coarser neps class, then air-jet yarn clearly shows better values than ring yarn.
- Compared to cotton and man-made fiber cellulose, polyester is more difficult to bond in the fiber bundle.
- Due to the higher fiber-fiber friction in the yarn, the mean strength with ring yarns, depending on the raw material blend, is approximately 12 – 20% higher.
- With the air-jet yarn structure, the number of undesired weak places and the variation in tenacity across the yarn formation process must be ensured, where necessary. This cannot be achieved by means of the polyester ratio.
- Air-jet yarn shows a significantly lower hairiness than ring yarn, in this case approximately 13 – 28%.

10.2. Two-Ply Yarn

- The twisting process shows clear advantages with air-jet yarns of better evenness and tenacity.
- The optimal twist for air-jet yarn becomes apparent with a twist coefficient of ae 3.3 and the opposite twist direction to the spinning direction. The same twist as spinning direction enables the possibility of using a very low two-plied twist factor and therefore cost reduction in the twisting process.

10.3. Weaving and Fabric

- The running properties in the weaving preparation as well as in weaving machine were faultless.
- The weaving process could be made without any sizing.
- With an increasing polyester ratio up to 67%, the fabric break load in the weft as well as in the warp direction substantially increases. Subsequently, due to the fabric bonding with an increasing polyester ratio, there is no further significant increase in the break load.
- With 80% lyocell ratio, the fabric tenacity can be around 10% lower due to the finishing process. With an increasing or high polyester ratio, however, there are no disadvantages in the fabric tenacity caused by finishing.
- The positive influence of the twisted yarn in terms of fabric pilling characteristics is greater than the yarn structure of the single yarns.
- The pilling characteristics are influenced by the following ranking:
  1. twisting process
  2. yarn structure
  3. raw material

10.4. Economy

- The manufacturing costs of ring yarns are approximately 33% higher in the case of Indonesia and around 35% higher for China than those of air-jet yarns.
- With an increasing proportion of polyester, the manufacturing costs decrease minimally. One of the reasons is found in the waste costs on the cards. These are with 100% polyester 0.6% and with 100% lyocell with 1.5% calculated waste.
- With air-jet yarn the yarn manufacturing costs show no difference with increasing polyester content, despite the lower waste costs using polyester because of the investment for a new technology facility like injection.

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