10. Recent Developments in Spinning and Non-wovens

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Learning objectives

On completion of this topic you should be able to:

- Describe the latest developments in worsted spinning including ring, collapsed balloon, and compact spinning
- Outline bicomponent yarns, two-folding, winding and clearing
- Outline developments in non-woven processing
- Describe cross-lapping, and compare bonding systems such as needlepunching, stitch and hydroentanglement

Key terms and concepts

Ring spinning, self twist, weavable singles, collapsed balloon, spinning triangle, compact spinning, bicomponent yarns, winding, clearing, two-folding, twisting, non-woven, carding, cross-lapping, bonding systems, needle-punching, stitch bonding, hydroentanglement

Introduction to the topic

Ring spinning (which is discussed in Topics 1 and 9) remains the dominant form of spinning wool into yarn, primarily because it is regarded as producing a superior yarn to alternative spinning systems. However, a number of modifications to long staple ring spinning have been developed in recent years to provide more versatility and to reduce costs. These include methods of eliminating two-folding (or plying) in the production of weaving yarns, with the ultimate aim of producing as a yarn as possible on a spinning frame without resorting to two-plying or sizing.

The manufacture of nonwoven fabrics involves converting fibres into fabric, eliminating the need for yarn to be spun as an intermediate step. The ability of wool to felt has enabled nonwoven (ie, felted) products to be made for centuries. However, more modern processes involving needle punching and stitch bonding enable a range of nonwoven products by mechanical means.

Useful references for this topic are Hunter (2002) and Crawshaw and Russell (2002).

10.1 Modifications to conventional ring spinning

Insertion of twist is very expensive. In fact, ring spinning is more expensive than the total cost of all the processes from scouring up to the spinning frame but it produces a yarn with the desired attributes. A lot of effort has gone into developing improvements to ring spinning in order to increase production and performance, and to reduce costs. These include methods to eliminate the need for two-folding of yarns or sizing of fine worsted yarns in order to make them weavable, ie, Sirospun, compact spinning and Solospun (Hunter (2002).

The improvements discussed here are:

- compact or condensed spinning – the claimed benefits include improved yarn strength and elongation, reduced yarn hairiness, improved weaving efficiency and less fibre attrition during knitting;
- collapsed balloon spinning – with this system, higher spinning speeds are possible;
- Sirospun produces a two-strand yarn in a single step from two roving strands;

- Solospun produces a weavable singles yarn in a single step from a single roving strand.

Open-end (OE) spinning, air-jet spinning and friction spinning systems have been developed but have not found widespread adoption for wool (see Reading – *Alternatives to Ring Spinning*). Short wool (40 to 45mm) is being spun on the OE system but the speeds achievable are not as high as for cotton. Contaminant build-up in the rotors is cited as a problem with OE spinning of wool.

Just as for the spinning of cotton and synthetic fibres, there has been a big move to automation in worsted spinning. Automatic doffing of full spinning bobbins has become standard where the full bobbins are removed from the spindles and replaced by empty bobbins. The empty bobbins are presented to the spinning frame on a conveyor and the full bobbins are taken away by the same conveyor. Using this conveyor system, the spinning frames can be directly linked to winders.

However, one problem that has had to be overcome in worsted spinning is that wool singles yarns are normally steamed before winding to reduce twist liveliness. Several companies have introduced in-line steamers where the bobbins are transported from the spinning frame through the in-line steamer on a conveyor before being presented to the winder. At the same time, winder manufacturers have also improved their machines to allow winding of twist-lively yarns by maintaining the yarn ends under tension. As part of the winding operation, pneumatic splicing is routine for wool yarns and quality splicing is particularly important for weavable singles yarns, where hot air splicing is recommended.

Two-folding in the form of '2-for-1' twisters (rather than ring-twisting) has become the standard method of producing folded wool yarns (see Topic 9 - Spinning).

There is strong demand to bring quality control in spinning on-line but at the moment it seems that it is too expensive to be introduced on the spinning frame apart from the detection of end-breaks. However, on-line quality control remains an important part of the winding process, with a number of associated automatic fault detection and clearing devices being available now. Although coloured fault detection was first developed to remove vegetable matter contamination in ecru wool, the technology has achieved large penetration in both the worsted and cotton sectors. Yarn hairiness can also be measured on-line during winding. Moreover, it is now possible, with electronic tagging of bobbins, to measure yarn quality in winding and generate a list of individual spinning frame spindles that need attention. In general, the demand for automation is increasing in high labour-cost countries while there has been a very marked trend for spinning to move to the low labour-cost countries in Asia and Eastern Europe.

10.2 Self-twist yarns

Self-twist yarn is produced by inserting alternating twist into each of two drafted strands of fibre and then bringing them together so that, in trying to untwist, they twist about each other. This spinning system was developed at CSIRO Textile & Fibre Technology and was launched in 1971.

The most convenient way of spinning staple fibres into such a yarn involves the use of a pair of rubber-covered rollers which both rotate and axially reciprocate in opposition (Figure 10.1). In this process, two strands of wool rovings are drafted and passed between the reciprocating rollers so that short sections of each drafted roving are twisted in one direction, and the next short section is twisted in the opposite direction, and so on. As the strands emerge from the reciprocating rollers they are immediately brought together, each strand then becomes twisted about the other to form a stable two-ply yarn. The action of the reciprocating rollers results in a short length of each strand having a twist reversal zone. To avoid the twist reversal zones being aligned when the two strands are brought together, the path lengths of each strand pair differs, resulting in the twist reversal zones being off-set.

Yarns produced by the self-twist spinning machine are suitable for knitting. However, in the commercial implementation of the process to produce weaving yarns, the wool self-twist yarn still requires a further twisting operation. Production speeds for self-twist yarns are up to 200 m/min. A typical four package machine is therefore equivalent to more than 50 spindles of a conventional ring spinning machine, which results in significant savings in floor space and energy.

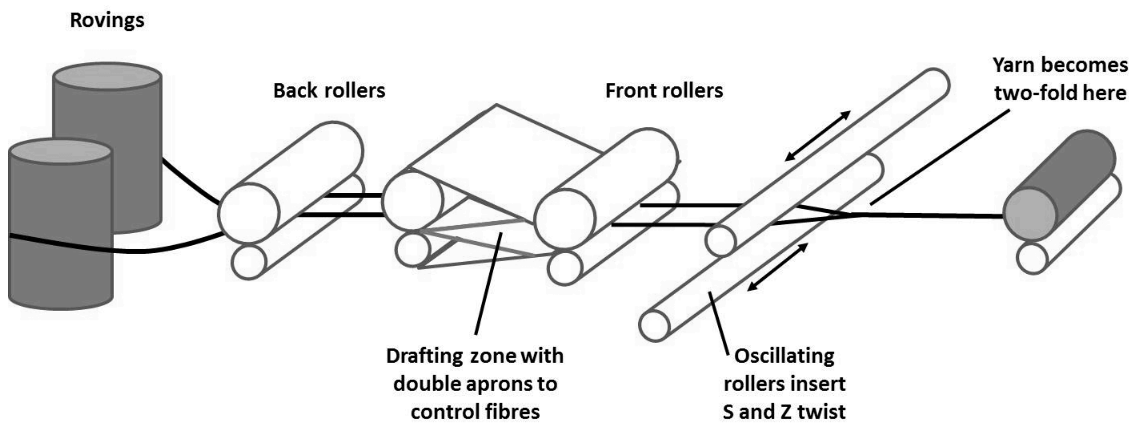

Figure 10.1 Self-twist spinning. Source: Wood, 2011.

Recently Macart Spinning Systems (UK) incorporated a self-twist spinning unit in their knitting yarn production system. In a continuous operation, this system manufactures yarn directly from slivers where the self-twist yarns are steam relaxed to introduce bulk in the yarn through fibre relaxation before being wound onto yarn packages. Production speeds up to 300 m/min are claimed.

Other alternative spinning methods to ring spinning, which is the dominant method for spinning wool and wool-rich yarns, are: open-end spinning, wrap spinning, air-jet spinning and friction spinning. These is discussed in the reading "Alternatives to Ring Spinning".

10.3 Development of weavable singles yarns

Sirospun™

Traditionally, two singles ring-spun yarns for weaving are twisted together to form two-fold yarns. This binds the surface fibres of the singles yarns into the twisted structure so that it is smoother and more resistant to abrasion during weaving. The arrival of Sirospun™, a development of CSIRO Textile and Fibre Technology in 1980 saw the adaptation of some of the self-twist discoveries to the ring-spinning technology of the worsted system. It was developed to address the demand for lighter-weight wool yarns and fabrics. It is a commercially-successful example of two-strand (or twin-spun) spinning, where a pair of rovings is fed separately to the same double apron drafting system.

The principle is that if two drafted strands of fibres are spaced apart but twisted together in spinning, then a number of fibre trapping mechanisms will operate to bind the surface fibres together. This fibre binding enables the yarn to withstand the abrasive actions experienced in weaving. Sirospun™ uses the torsional/friction forces involved in self-twist to bind two drafted roving strands together initially, and then applying twist to the two-fold structure in the conventional ring-spinning manner. Each strand receives some twist before they are combined at the convergence point after the front rollers.

The Sirospun™ attachments can be fitted to most conventional double-apron worsted spinning frames and involves a simple modification to the drafting unit of each spindle. This modification enables a spindle to draft two rovings into two separate strands and then twist them together. Sirospun™ uses a break out device to ensure that no singles yarn is produced when one of the strands breaks.

A Sirospun™ yarn has unidirectional twist and the fibres are not trapped as well as in conventional two-folding. However, with sufficient twist, fibre length and a similar number of fibres to the two-fold yarn, the weaving performance is satisfactory. Sirospun™ reduces spinning costs by an average of around 55%, but increases weaving costs a little because of slightly higher rates of yarn breakage.

Sirospun™ is especially suited to the production of light-weight, trans-seasonal 'Cool Wool' fabrics and was promoted by The Woolmark Company for this purpose. The system has two major advantages, the cost of two-folding is eliminated, and the productivity per spindle on the spinning frame is effectively doubled (Figure 10.2).

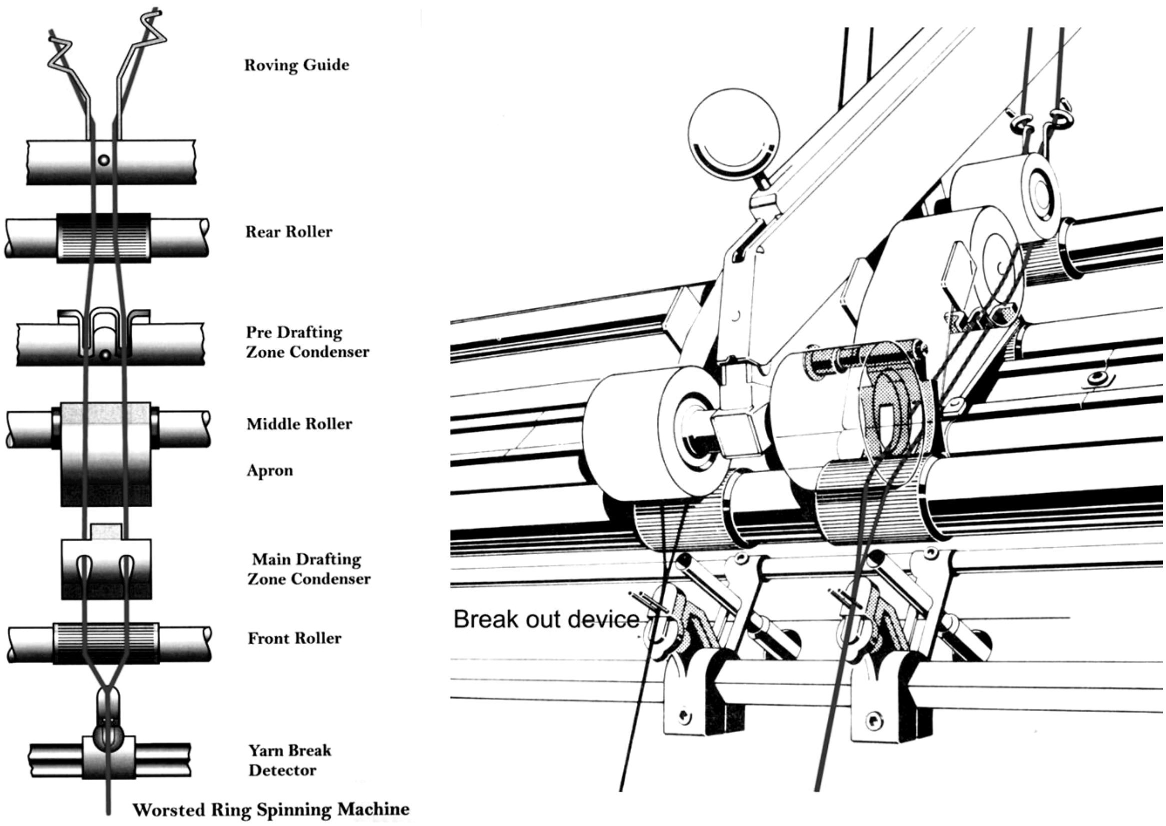

Figure 10.2 Sirospun™ spinning process Source: CSIRO TFT.

Solospun™

During 1998 a new spinning technology, Solospun™, was released as the result of collaboration between CSIRO Textile and Fibre Technology, The Woolmark Company and Canesis Network Ltd (formerly WRONZ). As the name suggests, Solospun™ produces a weavable singles yarn in a single step from a single roving. The Solospun™ technology is a simple, inexpensive, clip-on attachment to each spindle position on standard long-staple (worsted) spinning frames.

The attachment consists of a bracket that holds a friction pad and a pair of Solospun™ rollers (Figure 10.3). The bracket clips on to the shaft of each pair of top front draft rollers of the spinning frame, with each Solospun™ roller being positioned just below and parallel to, but not in contact with, its corresponding top front draft roller. The Solospun™ rollers are rotated by being in contact with the bottom front draft rollers. Unlike Sirospun, Solospun™ is spun from a single roving strand, so there is no longer a need for a double roving creel or breakout devices. However, the principle of inserting twist into individual strands prior to twisting them together to trap fibre ends can be attributed to the knowledge gained during the development of Sirospun.

Solospun™ differs from condensed, or compact, spinning in both application and principle. It achieves fibre security through the actions of localised twist in sub-strands and fibre migration. Condensed spun yarns, on the other hand, may still require two-folding or sizing to be suitable as warp yarns. Less twist is required which reduces fabric streakiness and higher spinning speeds are possible with much better spinning performance than can be achieved when spinning the singles yarns needed for a similar resultant two-fold yarn. The overall result is a very significant reduction in yarn production time and costs.

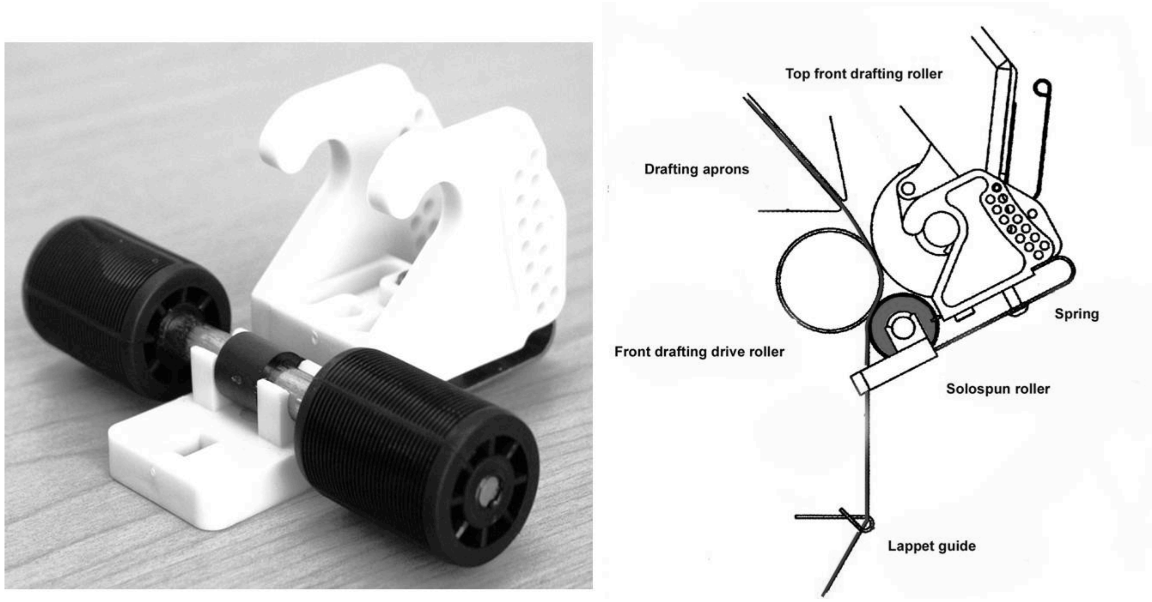

Figure 10.3 Solospun^{TM} components. Source: Wood, 2011.

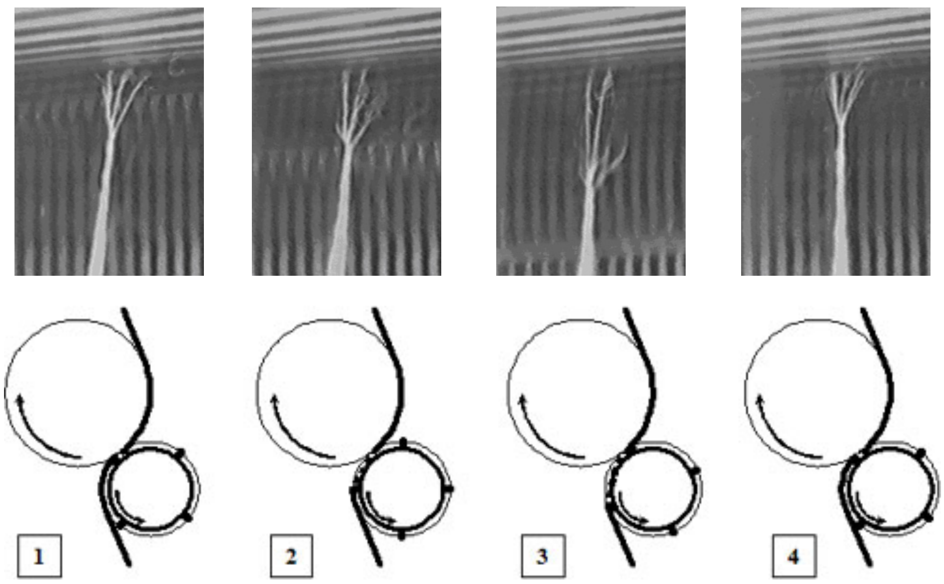

Figure 10.4 Solospun^{TM} spinning process. Source: CSIRO TFT.

1: A set of sub-strands form as a Solospun^{TM} roller land passes the bottom draft roller nip point.

2 & 3: The sub-strands move down into the slots and lengthen, varying the angles between each sub-strand.

4: A new set of sub-strands form as the next Solospun^{TM} roller land passes the bottom roller nip point.

The Solospun™ principle

As illustrated in Figure 10.4, the Solospun™ roller's operation is to interrupt the path of the drafted fibre strand, nipping it against the bottom front draft roller. The surface of the Solospun™ rollers is made up of four segments. As shown in the sequence in Figure 10.4, a 'land', which is flush with the roller surface and runs parallel to the roller axis, separates each segment. Between each land is a series of slots that are offset in each adjacent segment. The Solospun™ rollers act as intermittent twist blocks, preventing twist from reaching the fibres emerging from the front draft roller nip. The slots in the Solospun™ rollers divide the drafted fibre strand into a number of sub-strands as shown, which, through the intermittent twist-blocking action of the roller lands, converge at varied angles and rates to achieve a subtly entangled structure with locally differing twist levels.

Figure 10.4 illustrates how the varied angles and rates are achieved in one-quarter turn of the roller. Following the sequence from left to right, new sub-strands are formed after the main, drafted fibre strand has been nipped by one of the roller lands. As the land rotates away from the nip point, the sub-strands move down into the slots. As this occurs, the angles between the sub-strands increase. The continuing changes in these angles result in increased fibre migration and fibre trapping. When the next land reaches the nipping point, a new set of sub-strands is formed in the offset slots of the following quarter segment. This process is repeated every quarter turn, so that, depending on their length, fibres may undergo many changes in sub-strand position during twisting into the yarn. This action confers greater fibre security as fibres are trapped by neighbouring strands and by migration within and between strands.

Consequently, in comparison to equivalent singles yarns, Solospun™ yarns have fewer protruding fibre ends per unit length and increased abrasion resistance, making them weavable without the need for two-folding or sizing typically used in the cotton sector and increasingly used in the worsted sector.

With Solospun™, relatively even yarns of 25 – 50 tex can be spun, and compared to two-fold yarns, the savings in yarn production costs are estimated to be between 15 – 40%. The key advantages of Solospun™ over Sirospun™ are:

- Improved spinning performance;
- No need for two strands;
- Can operate at lower twist levels and with fewer fibres than the normal two-fold equivalent.

10.4 Collapsed balloon spinning

In conventional ring spinning, twist is inserted into a fibre stream to form a yarn through the action of a rotating spindle. As twist is being inserted in the yarn, it rotates around the spindle before it passes through a traveller that is rotating around and in frictional contact with a stationary ring. After passing through the traveller, the yarn is wound onto a bobbin. The spindle may be rotating at 10,000 rpm or more. As the yarn rotates around spindle, it balloons out. The yarn balloon is subject to air resistance and centrifugal force as it is being rotated. These forces exert tension on the yarn and is one of the limiting factors in production speed, with friction between ring and traveller being another limiting factor.

Over the last three or four decades, attempts have been made to reduce the tension in the yarn during spinning. One of the systems that has been adopted recently is known as the *collapsed balloon* system. This system has actually been adapted from the woollen spinning sector where a similar system has been in use for some time. By reducing in size (or eliminating) the yarn balloon, tension in the yarn is significantly reduced. The collapsing of the balloon is achieved by passing the yarn around a *spindle finger* attached to the top of the spindle (Figure 10.5). Tension measurements have shown that the mean yarn tension above the spindle finger is about 1/5 to 1/10 to that of equivalent yarn without a spindle finger.

The forming yarn is looped once or twice around the slightly bent spindle finger creating a capstan effect. This prevents the yarn balloon from forming such that the yarn path spirals around in contact with the bobbin (or the yarn that has already been wound onto the bobbin) before passing through the traveller and also being wound onto the bobbin. One consequence of the yarn-to-yarn contact during spinning is the teasing out of fibre ends from the yarn surface resulting in an increase in fibre ends protruding from the yarn surface; i.e. an increase in yarn hairiness.

The decrease in yarn tension can be utilized in a number of ways.

- Increase the spindle speed and hence increase yarn production
- Decrease the twist inserted, also resulting in an increase in production
- Spin yarns with fewer fibres in the cross-section resulting in finer yarns
- Substitute finer fibres with fewer coarser fibres (end product parameters permitting) to produce yarns of the same weight per unit length

Figure 10.5 Spindle finger. Source: Zinser (www.zinser-texma.com).

10.5 Air-condensed or compact spinning

The compact or air-condensed spinning system is an extra fibre stream control zone added to a spinning frame after the main drafting zone, before the twisting zone. The compacting zone uses air to reduce the width of the drafted, but untwisted, fibre stream to almost the same diameter as the yarn; see Figure 10.6.

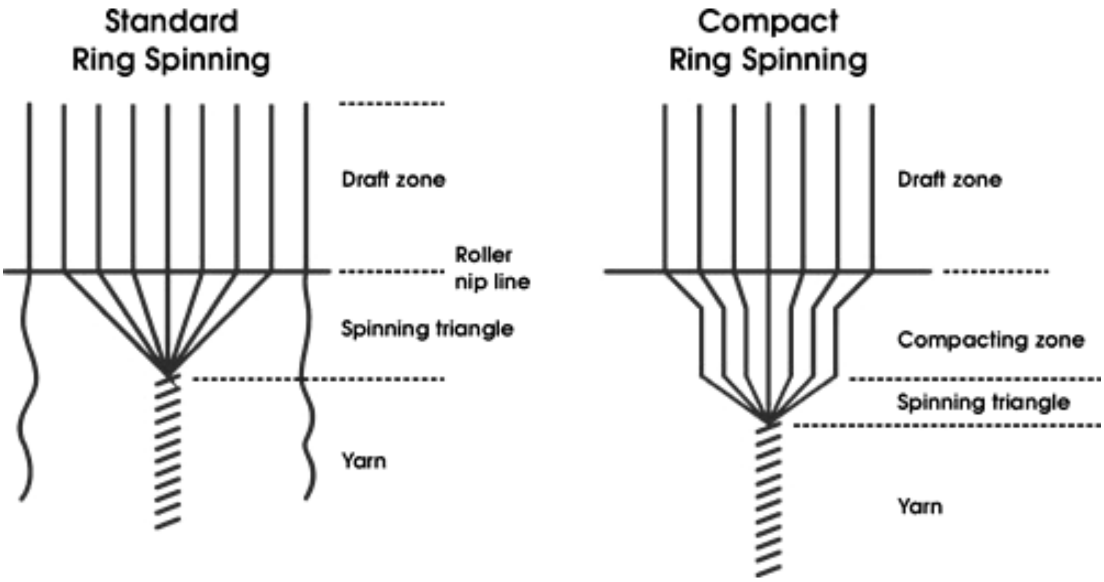

Figure 10.6 Compact spinning principle. Source: CSIRO TFT.

In conventional ring spinning, the drafted fibre stream has a width of a few millimetres. Twist is inserted in this fibre stream as it emerges from the front rollers of the drafting zone. The action of inserting twist consolidates the fibres (but not necessarily all fibres) into the yarn. This consolidation results in what is often referred to as the *spinning triangle*. The air-condensed spinning systems reduce the width and length of the spinning triangle, improving the control of fibre ends, resulting in fewer fibre ends poking out of the yarn, i.e. the yarns are less hairy. Reducing, or condensing, the width of the fibre stream after drafting is achieved by using a controlled stream of air to draw the fibre closer together.

It is claimed that, in comparison to equivalent conventionally spun yarns, the condensing system significantly reduces yarn hairiness, improves yarn tenacity and results in more even yarns. It is also claimed that because condensed spun yarns are stronger and more even, it would be possible to spin them at higher production rates than equivalent conventionally spun yarns. This would reduce the cost of spinning.

There are three variants of the condensed spinning system. Several variants (each manufactured by different spinning machine manufacturers) are used in the short-staple (cotton) spinning sector, and to date three systems have been adapted for wool worsted spinning. The three variants are as follows.

1. An apron system where air is drawn through a central line of small holes to consolidate the fibre stream. The apron can be either above or below the fibre stream; an example is shown in Figure 10.7.

2. A large diameter, perforated roller system. The perforations are situated in a central line around the circumference of the large diameter roller (Figure 10.8).

3. An air-permeable mesh apron system. The air-permeable mesh apron runs over an elliptical suction tube containing a slot, or slots, which may either be parallel to the fibre stream, or offset at a small angle to the fibre stream to effect consolidation of the fibres.

Figure 10.7 Compact spinning system Source: Zinser (www.zinser-texma.com).

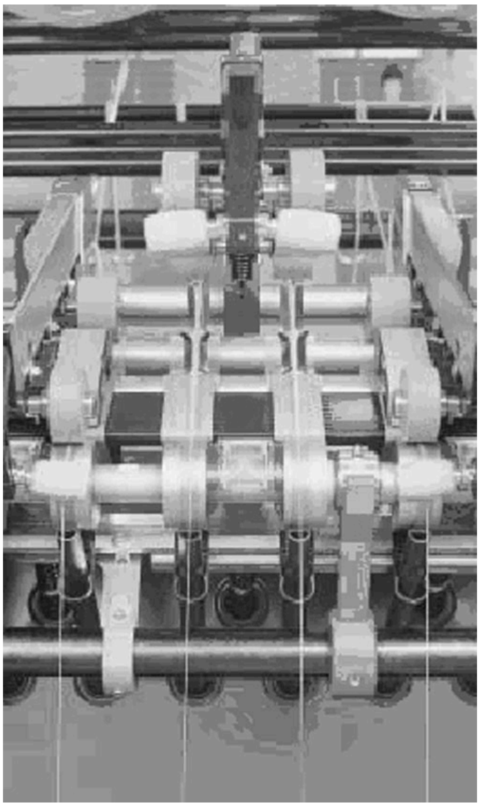

Figure 10.8 Compact spinning system. Source: Cognetex (www.finlane.com).

10.6 Bicomponent yarns

Core spun yarns incorporate a filament in the centre of a staple fibre yarn; i.e. the staple fibres are wrapped around a central filament. The filament can be a pre-formed yarn, single or multiple filaments of polyester, nylon or elastain (eg Lycra); the latter imparts a high degree of elasticity (stretch) to the yarns and fabrics. The filament is usually introduced to the staple fibre stream behind the nip of the front draft rollers. Guides and tension devices are required to align and control the introduction of the filaments. Figure 10.9 shows a typical core spinning system.

Wrap spun yarns involve the wrapping of filaments around a stream of staple fibres. The filaments may be wrapped around a twisted stream of staple fibres (i.e. a yarn) or an untwisted, parallel stream of staple fibres. Wrap spun technologies gained popularity during the 1970's, however, today they are confined to niche markets. Generally, fancy twisters are required to produce wrap spun yarns.

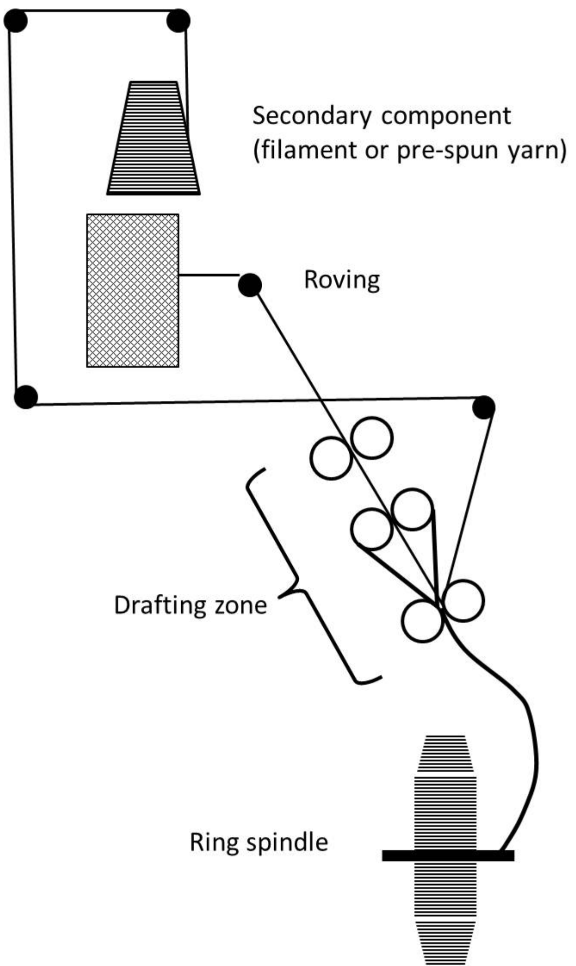

Figure 10.9 Bicomponent spinning. Source: Wood (2011)

Sirofil

A more recent bicomponent spinning development to produce wrap spun is the Sirofil system. This system is based on Sirospun technology. Instead of two wool fibre strands being spun, one of the strands is wool and the other is a filament, or a strand of multi-filaments. As the wool and filaments (spaced about 15 mm apart) emerge from the front draft rollers, they are twisted together, resulting in the filament(s) being wrapped around the wool. The Sirospun break-out devices, which ensure that both strands are broken if one fails for some reason, are modified to be able to stop the filament from being spun into the yarn in the event the wool strand fails.

10.7 Winding/clearing

Once spinning has been completed, the yarns are wound from their spinning bobbins onto larger packages. During this procedure the faulty sections of yarns are removed and the fault free yarns are rejoined, either by knotting or splicing. Knots themselves are yarn faults that may fail in subsequent processing, cause other faults in processing, or require labour for their removal during mending of the final fabric. The ultimate solution would be a yarn joint completely indistinguishable form the parent yarn. Today, knotting has been generally superseded by splicing, and CSIRO was involved in the development of splicing technology suitable for wool yarns, partly motivated by earlier work on Sirospun.

Yarn splicing

After the detection and removal of a yarn fault, and where the start and end of yarns from two spinning bobbins are to be joined, splicing involves the untwisting of the fibre ends at the two yarn ends to be joined, then bringing the two yarn ends together and inserting twist into the join. The splice must have the same appearance as the parent yarn (i.e. be almost invisible) and have almost the same strength. Two splicing systems have been developed by CSIRO for worsted yarns; mechanical and pneumatic. CSIRO has licensed the mechanical Twinsplicer technology to Savio (Italy) and the pneumatic Thermosplicer technology to Schlafhorst (Germany).

In the Twinsplicer (Figure 10.10), the yarn ends to be joined are sandwiched between two annular discs, which are geared together in such a way that they rotate in opposite directions around their central axes. To produce the yarn splice, the discs are first rotated to remove the twist over a short length of the two yarn ends to be joined. The untwisted ends are then overlapped and twist is inserted into the join by rotation of the discs in the opposite direction. Although initially developed for wool, the Twinsplicer is primarily used for cotton yarns.

The Thermosplicer for worsted yarns (Figure 10.11) was developed after the observation that heating wool fibres increased their flexibility. It works by rapidly heating the wool fibres above their glass transition temperature during the yarn joining phase of the splicing operation. At this temperature the memory of past stresses is lost. The fibres become more pliable and consequently are easier to bind into the splice. The result is a stronger, more invisible splice. Investigation has shown that hot-air splices in wool yarns, irrespective of yarn type or state, are far more abrasion resistant than cold air splices. In weaving, cold air splices recorded the highest failure rate. During fabric inspection, hot air splices were judged to require the least levels of mender attention.

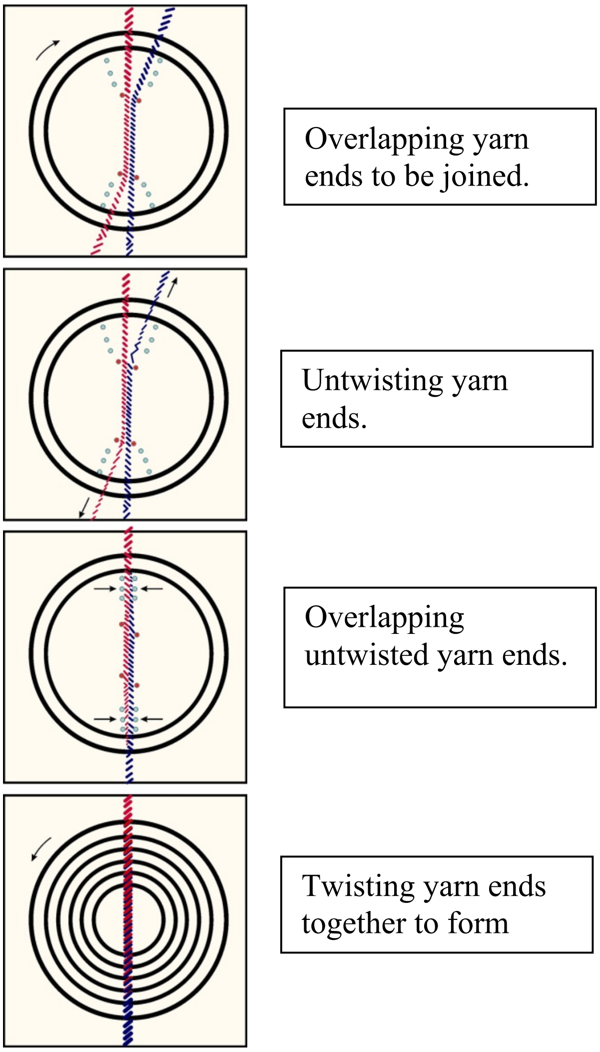

Figure 10.10 Mechanical splicer operation. Source: CSIRO TFT.

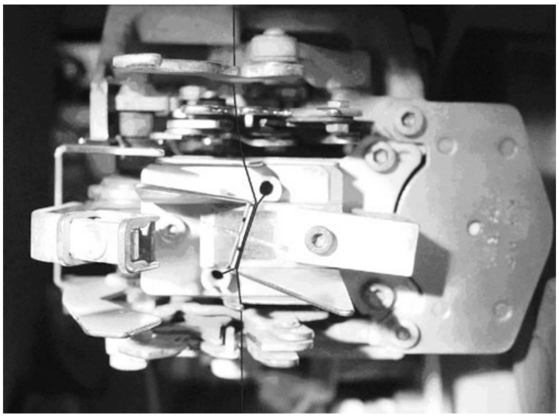

Figure 10.11 Thermosplicer (Hot Air Splicer). Source: CSIRO TFT.

During the winding operation, the opportunity is taken to monitor the yarns for faults. Traditionally, the yarns were monitored for thick and thin faults. It has now also become common practice to monitor ecru yarns for coloured contaminants such as vegetable matter, dark and medullated fibres, non-wool coloured fibres and grease contamination.

Siroclear (licensed to Loepfe) is an optical sensor incorporated into the thick and thick fault sensor to monitor the colour of the ecru yarn being wound; Figure 10.12. Both Loepfe and Uster incorporated sensing technology for the detection of polypropylene (undyed) in ecru yarn. The Loepfe technology is based on a triboelectric principle whereas Uster have combined a capacitance detector with an optical detector. Keisokki have also introduced an optical foreign fibre detector into their clearer technology. Any coloured contaminant or foreign fibre that is detected and falls outside preset limits is automatically removed and the yarn spliced as described earlier.

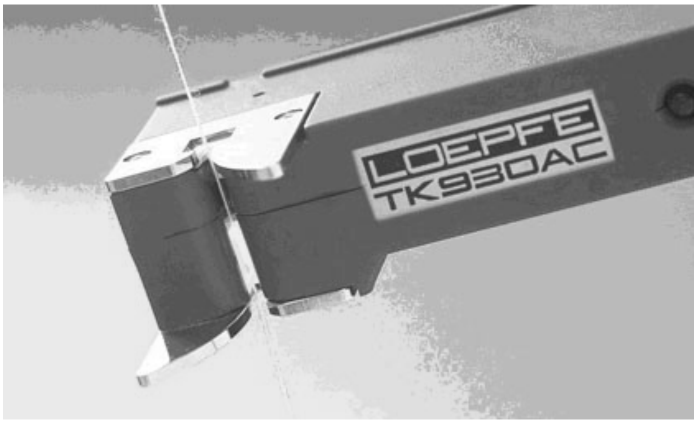

Figure 10.12 Loepfe yarn clearer incorporating Siroclear Sensor (Green Light). Source: CSIRO TFT.

Obviously, the preference is to minimise the presence of coloured and non-wool fibres, but one they are blended with the wool fibres, fibre-like contaminants are almost impossible to remove. Hence, CSIRO developed a system to detect and remove coloured contaminants early in the wool processing pipeline to prevent the contaminants being blended in to the wool. This system (Dark Lock Sorter licensed to Loptex) is typically incorporated in the fibre opening line after scouring. Recently, Loptex have introduced polypropylene detection into their sorter by incorporating an acoustic reflection measurement system. Another contaminant detection system developed by Jossi uses an ultra-violet light/fluorescence detection system into their sorter for the same application.

10.8 Non-wovens manufacture

While woven, knitted and tufted goods make up the largest quantity of textile fabrics produced, other fabric forming methods are available that do not require the prior making of a yarn, or weaving or knitting steps. These products, which are called *nonwovens*, are produced by the direct conversion of fibre to fabric. Nonwovens have a wide range of applications, which include home textiles, personal hygiene products and technical textiles. As well as the unique products that can be made by the nonwovens method, a major advantage is the relatively low cost of manufacture.

Conventional textile fabrics use yarns to form a fabric, with interlacing of the yarns through weaving or knitting to provide strength. On the other hand, in nonwovens single fibres are assembled to form a web of directionally and randomly oriented fibres, to which some means of fibre bonding is applied to provide the required web strength.

Felts, a traditional type of nonwoven are formed from wool and other animal fibres. These fabrics can be divided into:

a) true felts, which are formed by agitation of a random wool web in the presence of water, and
b) needle felts, where the fibres are intermingled by mechanical action, ie, needle-punching.

The other main types of nonwoven products, more common in today's markets, are the bonded fabrics, which are mostly made of synthetic fibres. These comprise two types:

1) Chemically-bonded nonwovens
2) Mechanically bonded nonwovens.

Limitations of nonwovens

Woven, knitted and nonwoven fabrics can be compared as follows:

(a) Woven and knitted fabrics

- Within yarns: intimate fibre contact gives strength and elasticity
- Between yarns: looser linkages, yarn crimp
- Drape, bulk, good handle

(b) Nonwovens

- Intimate fibre contact throughout is required to get strength and fibre security, leading to:
    - stiffness
    - poorer handle
    - poor drape
    - poor stretch recovery

The strength and elasticity of woven and knitted fabrics is provided by the yarns, the yarn crimp, and the yarn arrangement. This allows high fabric strength and good fibre security within the yarn while the fabric's flexibility and fluidity is provided by the looser links between the yarns. Nonwovens cannot easily imitate this effect because the strength and fibre security of the nonwoven is derived from fibre entanglement throughout the fabric. These short-comings currently restrict nonwovens to certain applications; these include industrial fabrics and medical and safety apparel but some consumer apparel products are well suited to nonwovens and research is continuing to overcome the limitations and widen their applicability.

Although the significant savings possible in manufacturing make nonwovens attractive, the inherent physical limitations of nonwovens suggest that weaving and knitting will remain the favoured wool fabric production processes for the foreseeable future.

10.11 Non-woven processes

Nonwovens production involves several processing stages:

- web formation
- batt formation
- consolidation and bonding
- finishing
- colouration

Web formation

Web formation for staple fibres is usually via a carding process; an alternative is air-laying.

The schematic diagram of Figure 10.13 shows carded web formation. One possible bonding route that may follow carding is chemical binder impregnation. The binder is applied as an emulsion or foam and then dried and cured by continuously passing through an oven to glue the fibres together. This process is commonly used for the manufacture of light weight fabrics for disposable wipes but is also used to make, for instance, wool blend vertical blinds, usually with stitch bonding, see later. For lightweights, the web produced goes directly into the binding process, for heavier fabrics several cards can be positioned in line and their webs combined. The fibre orientation leaving a card is usually predominantly in the machine direction, even though condensing rollers may be used on the outputs. This leads to the strength being greater in the machine direction (MD) and weaker in the cross machine direction CMD. This leads to a high MD/CMD ratio, which is undesirable for some applications such as wool apparel.

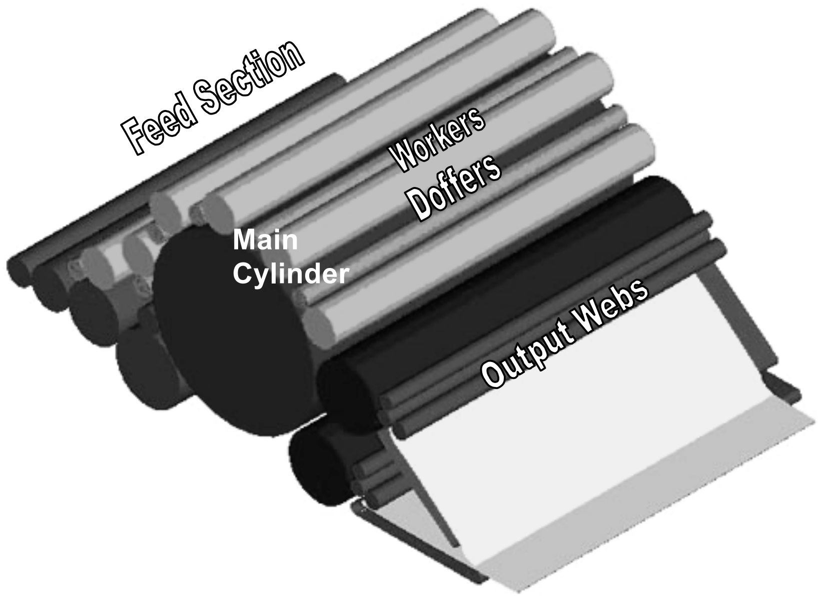

Figure 10.13 Basic nonwoven card. Source: Prins and Finn, 2006.

Condenser rollers (shown in Figure 10.14) are a pair of rollers positioned after the doffer covered with special wire and that bring the speed down in steps. Each roller is slower than the one before and so the web is crammed into the wire of the following roller changing the fibre orientation. This also has the added effect of increasing the doffer speed while keeping the line speed the same, the higher doffer speed takes more fibre from the card per revolution of the main cylinder and so lowers the total fibre load of the card and can allow higher production rates. The desire to increase productivity while maintaining quality has led to nonwovens cards with three doffers being developed (FOR, Spinnbau). The three doffers further increase the rate at which fibre can be cleared from the main cylinder allowing higher throughput and also lead to further averaging of random web variations to improve quality. Heavier web weights are also then possible.

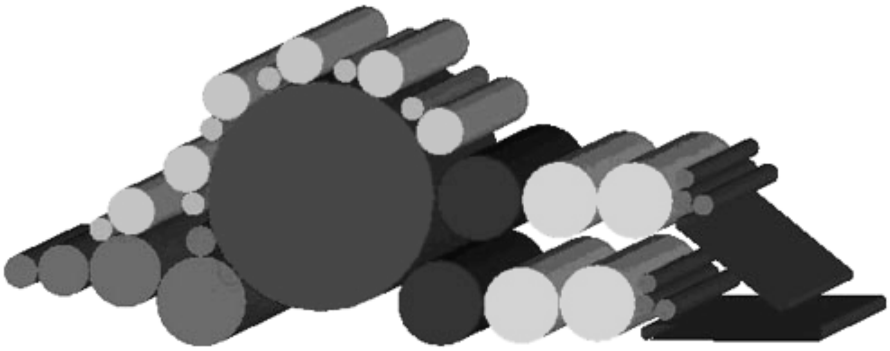

Figure 10.14 Schematic diagram of a typical nonwoven card with condenser rollers, (e.g. Thibeau, Spinnbau, FOR). Source: Prins and Finn, 2006.

A recent development has been the random card. This card has an extra roller between the doffers and the main cylinder with special wire, see Figure 10.15 below. This roller turns counter to the main cylinder and partially strips it, the transfer is said to be mostly via air-flows and a more random orientation is produced, MD/CMD is claimed to come down to 3:1 and with condenser rollers down to 1.5 : 1.

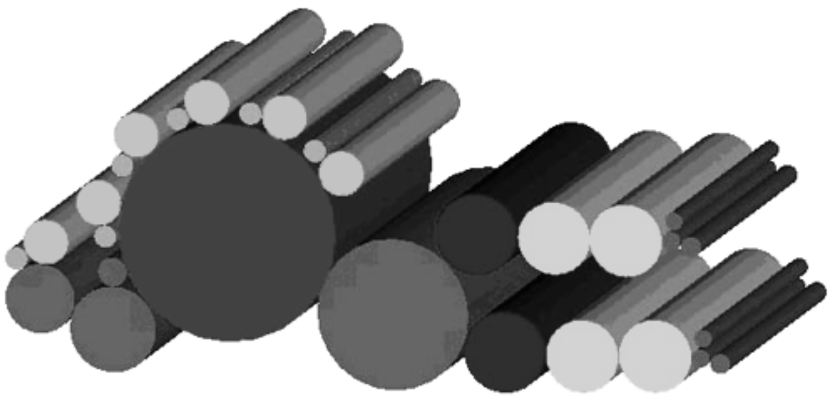

Figure 10.15 A random card (extra counter-rotating roller between cylinder and doffers). Source: Prins and Finn, 2006.

Many new high speed nonwoven cards from, for instance from Spinnbau or Thibeau, have suction systems to control the web as it is doffed at high speed. This has lead to improvements in web quality and production rate. The Turbo card from FOR uses aerodynamic stripping of the workers instead of stripper rollers. The FOR cards now also have a high speed doffing system that does not use suction and is claimed to allow heavier webs to be produced from the card. Another interesting development in carding is the Sirolock card wire from ECC. This has steps in the teeth profile to increase fibre retention. It has been used successfully on workers on and doffers, on a worker the increased retention would improve blending power and on a doffer it would increase the fibre transfer rates, reducing card loading at high production rates.

Cross-lapping

To produce heavier weight fabrics (batts) from a single card, a cross-lapper is used (Figure 10.16). This device layers the light-weight web leaving the card with the layered web leaving the cross-lapper at 90^o to the card direction. The ratio of the card speed to the cross-lapper output speed determines the number of layers and the weight of the cross-lapped web. In this case the predominant fibre direction has become across the fabric; the MD/CMD ratio is then less than 1. The heavy cross-lapped web can be drafted, or stretched, to pull the fibre orientation towards the machine direction, in this way MD/CMD ratios close to 1 can be achieved. Cross-lapping and needle punching can produce variations in the density of the fabric across its width. The latest nonwoven Card - Cross-lapper systems have computer control such that the card speed and cross-lapper speed can be varied to change the web weight as it traverses the fabric giving a predetermined profile in density leaving the cross-lapper such that when the fabric is needle-punched provides a very flat density profile.

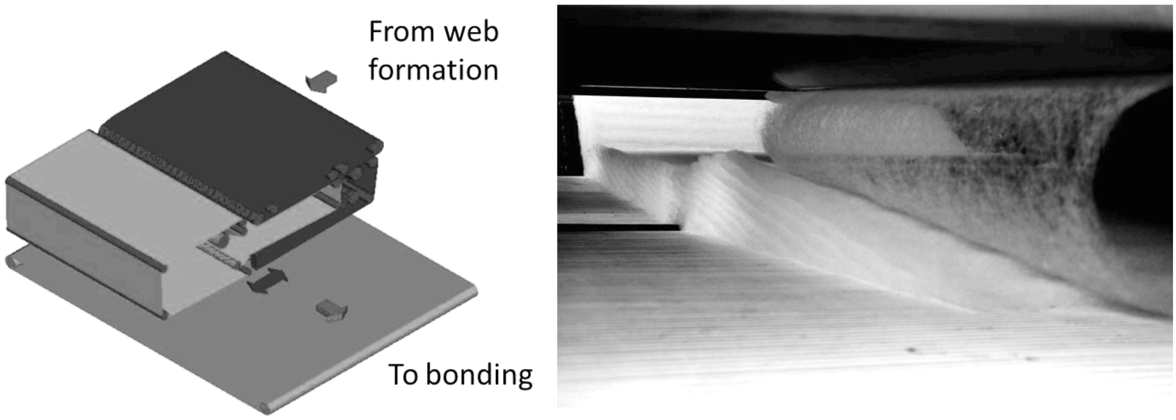

Figure 10.16 Cross-lapper. Source: Prins and Finn, 2006.

An alternative to cross lapping is to use a recently developed “turbo” and “Airweb” doffing systems from NSC or Spinnbau. These use a conventional card followed by a new system that throws the fibres into an air-stream to be collected suction onto a drum or belt to give a randomised pattern of orientation. These devices are claimed to produce MD/CMD ratios down to 1.2 directly. The output speed can be reduced to produce quite heavy webs without cross-lapping and high bulk is also possible with some fibre orientation in the vertical direction.

Consolidation and bonding

Figure 10.17 shows the needle-punching process which is very commonly used to manufacture medium to heavy weight fabrics. The needles are used at a density of several thousand per square metre and reciprocate through the fabrics. The barbs on the needles catch the fibres and entangle them to form a felted fabric. Often several stages of needling from each side of the fabrics are required to give the fabric sufficient strength. Because of the reciprocating motion the speed is limited by the “advance per stroke”, the fabric cannot be pulled forward while the needles are in the fabric without damaging either the fabric or the needles. A fairly recent development is the Hyperpunch system where the needles follow an elliptical path rather than straight up and down so that they partially follow the fabric as it advances through the needle-loom. Over needling can lead to excessive fibre breakage and so there is an optimum level of needling with respect to fabric strength.

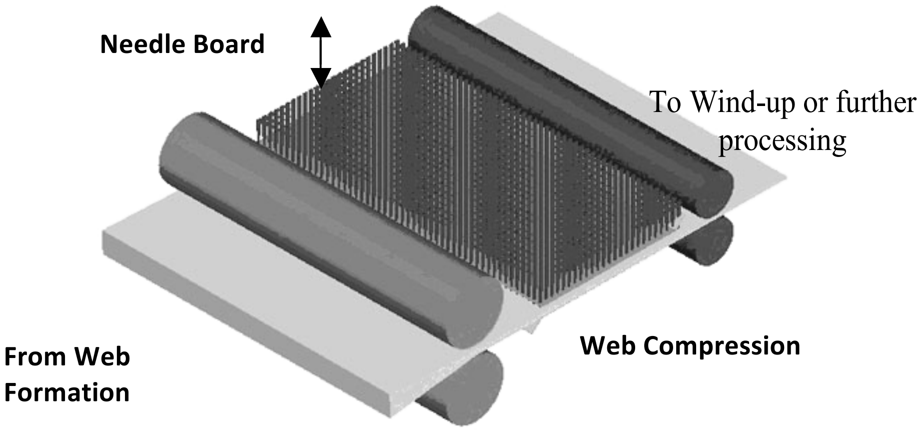

Figure 10.17 The needle punch process. Source: Prins and Finn, 2006.

For wool nonwoven textiles, an attractive needling process is the velour needle punch. This machine needles the fabric into a brush underneath rather than into a steel stripper-plate with a hole for each needle to strip the fibres from it. The velour needle punch pushes the fibres through the fabric to the opposite surface in a controlled way and produces a velour or velvet-like finish to the fabric. The fabric can also be patterned in this way by using special arrangements of needles and brushes.

Stitch bonding

Because nonwoven fabrics need to derive their strength from the intimate entanglement of the fibres and this leads to their stiffness relative to wovens and knits a compromise is reached in pure-fibre nonwovens between handle and performance. However, nonovens can be reinforced so that the fibres can be more loosely entangled but the strength is provided by the reinforcement. In stitch bonding sewing threads are inserted by sewing needles aligned across a cross-lapped web. The threads provide mostly machine direction strength while the natural fibre orientation of the cross-lapped web provides the CMD strength. The sewing threads, constituting only about 5% of the fabric weight, are buried into the fabric in finishing where a pile may be raised or the fabric lightly wet-felted so that they are not visible in the final garment. Such wool and wool-blend fabrics can be used in outwear and are limited to heavier than around 250g/m^2. A fleece-like fabric can also be produced in this way.

An alternative to stitch bonding to give extra strength is the use of a “scrim”. These are woven fabrics that are incorporated into the nonwoven, usually by insertion between two webs before bonding. Needle punching the webs through the woven fabric can produce a strong fabric with a lower degree of entanglement and so give a softer fabric. However, the fibre security can then be low and pilling and fibre shedding can become a problem. The cost of the woven fabric often has to be low and so synthetic fibres are used and for disposables often welded nets are favoured. However, for highly specified technical fabrics such as some wool-containing paper-making felts the scrim is a carefully designed key component rather than a cheap reinforcement.

Hydroentanglement

Hydroentanglement uses rows of fine high pressure water jets to entangle the fibres of the web into nonwoven fabrics (Figure 10.18). The water from the jets is removed by suction slots behind each injector. Because there are no reciprocating parts the production speed is not limited as needle-punching is by “advance per stroke”. The speed can be very high and is limited only by the energy that can be injected by the water jets into the entanglement process. Speeds of hundreds of metres per minute are used on lightweight synthetic fabrics for disposables but lower speeds are often used for heavier or more durable fabrics. Power consumption is relatively high but the energy cost per kg remains low because of the high production rates possible.

The fine, high pressure water jets are applied against the fabric backed by either a mesh belt or a drum. The drums have mesh shells designed to improve entanglement and reduce striping by the jets. Spunlace process speeds may exceed 300m/min but are usually much lower, especially for wool which is harder to entangle than finer synthetic fibres.

Common spunlace products are:

- Wipes, towels, tissues
- Filters
- Protective apparel
- Surgical gowns and covers
- Synthetic leather
- Sanitary products
- Home furnishings
- Interlinings (some wool)

Spunlace fabric weights have an upper limit, if the fabric is to be entangled throughout its thickness, of about 400g/m^2. The main advantage of the Spunlace process for wool is that lighter-weight fabrics can be produced compared to needle-punch nonwovens. Also a higher degree of entanglement can be achieved with less fibre damage compared to needle-punching. Reinforcing scrims can also be used in spunlace fabrics to add strength. While there is currently very little commercial production of spunlace wool fabrics, research and development is ongoing and is expected to provide commercial outcomes in the near future.

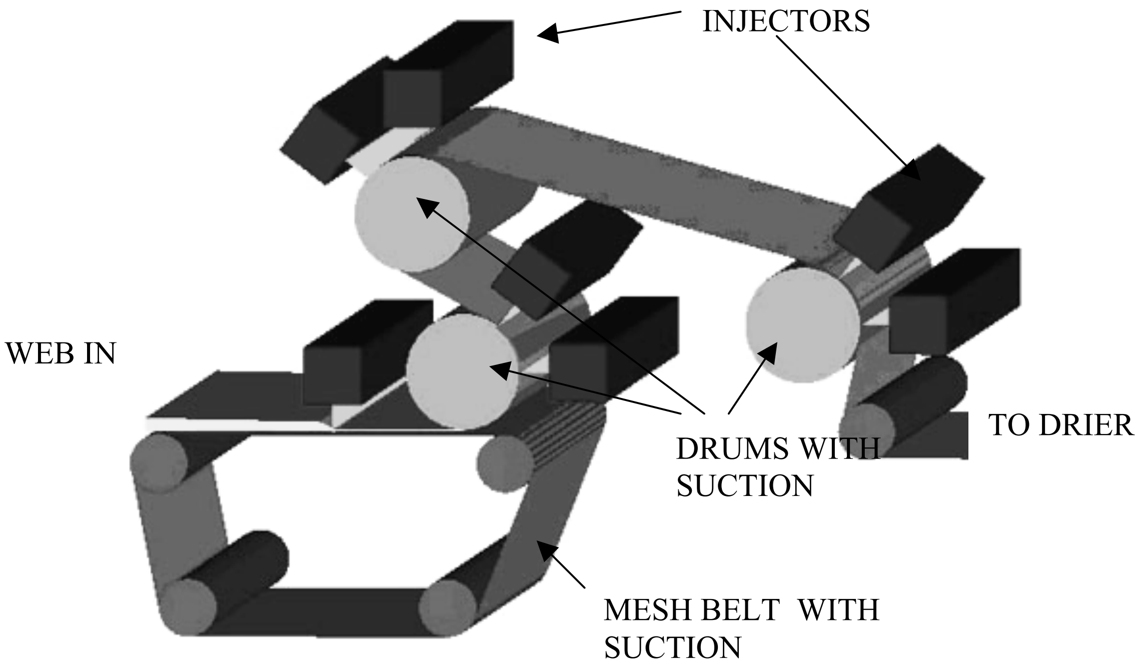

Figure 10.18 Hydroentanglement process Source: Prins and Finn, 2006.

Nonwoven fabric finishing

The production of nonwoven fabrics is carried out as either a continuous process, with fibre or resin as the input material and a roll of fabric as the output, or as a series of batch processes. Correspondingly, fabric finishing is carried out either in tandem with web formation and consolidation or off-line as a separate operation.

Slitting and winding are common finishing processes for all nonwoven fabrics that are produced in roll form. Roll width is determined at the slitting operation and roll length is determined at the winding operation. The dimensions of nonwoven roll goods are varied to accommodate the fabric end use or subsequent processes.

Nonwovens may be given a range of finishing treatments in order to enhance fabric performance of aesthetic properties. Performance properties include functional characteristics such as moisture content and transport, absorbency, repellency, flame retardancy, electric response, abrasion resistance and friction behaviour. Aesthetic properties include various attributes such as appearance, surface texture, colour and odour.

Nonwoven finishing processes can be categorized as being chemical, mechanical or thermal-mechanical.

Chemical finishing

This involves the application of chemical agents as coatings to fabric surfaces or the impregnation of fabrics with chemical additives or fillers. In many cases chemical finishing is an extension of the binder application process.

Generally, the coating process is applied to enhance the properties of the nonwoven structure. The coating may be applied as a continuous covering or as a pattern. The coating material is frequently applied as a solvent, aqueous solution or molten polymer. When working with many nonwoven substrates, special care must be taken due to the delicate nature of the structure itself or the arrangement of fibres on or near the fabric surface.

Mechanical and thermal finishing

Mechanical finishing involves altering the texture of fabric surfaces by physically reorienting or shaping fibres on or near the fabric surface. Thermal finishing, such as calendaring, enables structural changes to be permanently set into the fabric by the application of heat.

Surface structures may be established by embossing, compressive shrinkage (creping) and by creating loops or pile. Surface textures, ranging from flat and smooth to raised and leveled, may be altered by calendaring, sueding, napping, polishing, brushing and shearing.

In general, mechanical finishing processes operate at speeds lower than web consolidation processes, and consequently are carried out offline or as separate batch processes.

- Smooth surfaces are normally produced by **calendaring**, a process which subjects the fabric to pressure between two rollers for a controlled time and temperature.
- In **sueding** the fibres on the surface of a lubricated fabric are cut by the abrasive action of a high speed sanding roller.
- The **napping** process raises fibres to the surface of a lubricated fabric by withdrawing the fibres from the interior of the fabric. The napping action takes place was the wires of the working rollers penetrate the fabric, withdraw fibres and form a nap of raised fibres on the surface of the fabric. A wide range of loop or velour surface effects can be produced.
- In **polishing** the pile of a raised fabric surface is selectively oriented. The mechanical action of the rotating edge of a spirally-grooved, heated cylinder against the tensioned fabric surface results in a static electrification of the pile fibres, which orients the fibres in a parallel fashion. Rotation of the spiral roller in the direction that momentarily entraps fibres in the grooves results in a raised parallel pile surface. Rotation of the spiral roll in the opposite direction produces a flat, parallel pile surface.
- **Brushing** lifts the fibres to the fabric surface, and orients the raised fibres along the machine direction of the fabric.
- **Shearing** cuts raised fibres to uniform heights using a series of spirally wound shearing blades rotating over a stationary blade. Shearing usually follows a brushing operation

Wool requirements for nonwovens

The wools used in nonwovens manufacture are usually similar to those chosen for woollen processing, i.e. shorter fibre than for worsted and usually free of vegetable matter and so carbonised wool and broken top is used. Broken top is shorter wools that have been combed to remove VM, very short fibres and neps and is expensive compared to carbonised wool. As with woollen processing, it is also possible to piece-carbonise the fabric having made it with low VM wools but this is rare and the VM may cause other problems in the nonwovens plant if it is not dedicated to this wool process. Blends of wool and synthetic fibres are also possible; a huge range of fibre blends are commonly used in nonwovens processing.

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The following readings are available on the web learning management system:

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Summary

Ring spinning remains the dominant form of spinning used for wool, primarily because it is seen to produce a superior yarn to alternate spinning systems. Several improvements to conventional long staple ring spinning have been developed to provide versatility and reduce costs. Examples are:

- compact or condensed spinning – the claimed benefits include improved yarn strength and elongation, reduced yarn hairiness, improved weaving efficiency and less fibre attrition during knitting;
- collapsed balloon spinning – with this system, higher spinning speeds are possible;
- Sirospun produces a two-strand yarn in a single step from two roving strands;
- Solospun produces a weavable singles yarn in a single step from a single roving strand.

“Nonwovens” is a term used to describe textile products made via manufacturing processes that form fabrics without going through a yarn formation step; they are neither woven nor knitted. The fibre is formed into a web and then bonded, either chemically, thermally, by mechanical entanglement, or by combinations of these. This section describes these processes generally but with particular reference to wool.In nonwovens, processing fibre is converted directly to fabric in a single continuous process.

There are several ways of consolidating and bonding the webs together in non-woven processing including needle punch, stitch bonding and hydroentanglement

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Glossary of terms

Batt	Lofty and loosely-held fibre network (see Web)
Bobbin	A tapered, cylindrical tube placed over a **spindle** on which yarn is wound during the spinning process.
Crimp	Wave-like pattern typically seen in wool fibres and refers to the waves per unit length [eg waves (or crimp) per cm].
Crosslapper	A machine that continuously lays a web so that its fibres are oriented in a cross direction. The operation is called crosslapping.
Doffing	The replacement of the full **bobbins** (have spun yarn wound onto the full length of the bobbin) with empty bobbins.
Ecru	Undyed fibre, yarn or fabric; i.e. retaining its natural, or raw, colour.
False twist	Twist that is imparted to a fibre stream as it is drawn towards a twisting device, but loses the imparted twist once the fibre stream passes through the twisting device. The twisting devices can include devices such as an air jet, a rotating ring or cylinder, a pair of opposed oscillating rollers.
Fasciated yarn	Where the surface layer of fibres are twisted around the circumference of a yarn with decreasing twist to almost zero twist of the fibres located toward the centre of the yarn.
Filament	A fine, “continuous” length of polymer.
Hydroentangling	A web-formation process using high velocity water jets to wrap individual fibres, also called jet lacing or spun lacing.
Long staple spinning	Refers to the system used to process the longer wool and wool blends in the **worsted** sector; average fibre lengths are typically longer than 50 mm.
Needlepunching	A method of mechanically interlocking and consolidating fibre webs using barbed needles to re-position some of the fibres from a horizontal to a vertical orientation.
Nonwoven	A fabric consisting of an assembly of fibres oriented in one direction or randomly and which is held together by (1) mechanical interlocking, (2) fusing of thermoplastic fibres, (3) bonding with an adhesive agent.
Ring spinning	A continuous system of spinning in which twist is inserted by using a circulating **traveller**. The yarn is wound onto the **bobbin** since the rotational speed of the bobbin is greater than that of the **traveller**.
Short staple spinning	Typically refers to the system used to produce yarns from cotton, cotton blends and man made fibres of similar length; average fibre lengths are typically shorter than 50 mm.
Singles yarn	A single strand of yarn.
Sizing	The coating of synthetic starches onto warp yarns (yarns that run along the length of the fabric) to cover the fibres ends protruding from those yarns so that weaving efficiency is improved.
Spindle	A long thin (tapered) rod that is rotated to impart twist into textile materials. The **bobbin** on which the yarn is wound is placed over the spindle.
Web	Thin sheet of fibres which are loosely held together by inter-fibre friction or a bonding agent.
Traveller	A metal or plastic component through which yarn passes on its way from the yarn balloon to the **bobbin**, or package, surface in **ring spinning** or twisting. The traveller is mounted on a ring and is dragged around by the yarn.

Triboelectric	Frictional electricity; when two dissimilar substances are rubbed together, they become oppositely electrified; and if either is an insulator, it retains a charge.
Twist-lively	The state where the fibres twisted together to make a yarn still retain a “memory” of their untwisted state creating a torque imbalance in the yarn such that it will twist upon itself when not being held under tension, forming loops or snarls.
Two-folding	The twisting together of two **singles yarns**. Also called ‘plying’.
Wrap-spun yarn	A continuous filament yarn is wrapped around a core of untwisted staple fibres.
Worsted	Yarns spun wholly from combed wool in which the fibres are reasonably parallel and fabrics or garments made from such yarns. Worsted yarns require a greater number of processing steps than other systems to arrange the fibres in a reasonably parallel state in preparation for spinning.