Wool processing: fibre to fabric

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The miracle of transformation

A comparison of the fleece on the sheep's back and on the shed floor, with the attractive, highly desirable garments created from it can easily excite a sense of wonder. In the shorn fleece, the quite ordered array of the staples on the sheep has already been disturbed and the variable length and state of the wool from different parts of the body is obvious. Compare the wool shorn from the neck, head, belly and crutch with that from the sides and back. There will be differences in the vegetable matter in these components and there will also be differences in fibre diameter and colour. Add to all this a significant amount of wool wax or grease, together with some dirt and unseen sweat salts. All this variability exists on one sheep, yet a consignment of wool may contain fibres from many sheep, flocks and environments from across Australia.

How is it possible to profitably re-order and reassemble the fires in shorn wool to create fine smooth suiting fabrics, soft pliable knitwear, warm bulky woollen spun fabrics and cool lightweight shirting – and to do it in such a way that there is the required uniformity of technical properties and quality in the consignments, batches and deliveries through the textile pipeline?

That is the purpose of this unit, although the technical depth of the discussion is necessarily limited. Major issues are costs, blending or homogeneity, removal and disposal of contaminants, management of fibre entanglement, degree and limitations of control of fibre position and number within slivers and yarns, and uniformity of treatment within and between batches through the pipeline. There is also the major issue of specification and predictability of processing and product performance to meet quality and price demands. Several of these issues are worth briefly examining in detail.

The unbreakable law of randomness

Unfortunately, nobody has been able to devise a practical process whereby staple fires, such as cotton or wool, can be made to lay head to tail. All we can do, and usually the best we can do, is randomly lay fibres along an assembly direction such that the mean or average number of fibres sampled at many points along the assembly matches the linear density we require. But we must expect that there will be a variation in the numbers that we gather, simply because the process is to a degree out of control. It is exactly the same situation when collecting raindrops in a rain gauge. Suppose there are 100 drops on average caught by the gauge per minute. Provided the process is truly random and that the rain is uniform in time, a measure of the variation or standard deviation of the set of numbers of raindrops caught in intervals of one minute is given by the square root of the mean, or 10. Approximately two thirds of the counts will lie between 90 and 110.

The coefficient of variation (CV) is the standard deviation divided by the mean multiplied by 100. Thus, the mean number of drops is 100, with a CV of 10 per cent.

If the average number of fibres in a yarn cross-section is 36, there will be a very significant probability that at points in the yarn cross-section there will be less than 34 or even 28 fibres; one and two standard deviations from the mean respectively. This has implications for spinning performance, mean yarn strength, yarn extensibility and onward processability in general. And this is without considering the variability in mass per unit length of the yarn, which can arise from variability in fibre diameter, both within and between fibres, and from factors that may be less than optimal in processing.

As we move through the line, question whether the uniformity of the stock is governed largely by this random limit, or by other factors.

Fibre control

Drawing of slivers and rovings is achieved for wool, as for other staple fibres, by passage through a draft zone in which the speed of the output (or front) rollers is a multiple, the draft, of the input (or back) rollers. Fibres will in general be shorter than the distance between the rollers – the ratch. Of key importance is the way in which fibres that are not held by either set of rollers are controlled. The speed of these floating fibres will be intermediate between front and back rollers. Straightness is maintained by arranging for the leading ends of these fibres to be in contact with the trailing ends of fibres gripped by the front rollers, while the trailing ends contact fibres still gripped by the back rollers. Fibre-to-fibre contact is achieved by applying controlled pressure to the fibre strand in the drafting zone in a variety of ways. The ideal is to have fibres move individually, rather than as groups.

Watch for the means of fibre control which set wool processing apart from short staple systems like that of cotton.

Fibre entanglement

Whenever two or more fibres are entwined or knotted they move together as a unit. A common example in slivers and yarns is the nep. Entanglements move drafting away from the ideal behaviour of independent fibre movement and control. They result in a decrease in uniformity and unwanted visual defects on the surface of yarns and fabrics.

It follows that in order to minimise entanglements there must be some point in the processing of wool where fibres are essentially individualised.

Entanglement can easily take place in aqueous media, where the differential frictional effect between fibres, caused by the surface scale structure of the fibres, facilitates felting.

Fibre damage

Wool is a relatively weak fibre having a breaking strength of about 12cN/tex. In comparison, cotton and polyester have strength about twice or four times that of wool respectively. It is chemically weakened in alkaline solution particularly at higher temperatures, but damage also occurs during dyeing, which is normally carried out at low pH. Dyers are concerned to ‘get it right first time’ as extra dyeing to correct shade adds to damage. While wool has a relatively high extensibility at break, particularly as the moisture content is raised, it is easily damaged in mechanical processes and optimal lubrication is essential.

Fibre set

The wool structure contains chains of proteins that are cross-linked with disulphide bonds. Mild application of heat and moisture will induce temporary set. This is useful in pressing creases and reducing twist liveliness in freshly spun yarn. At higher temperatures the disulphide bonds can be broken and then rejoined when the temperature is reduced. This is used to advantage in imparting permanent set to fabric in order to improve dimensional stability, drape and handle. The dyeing process imparts permanent set to wool fibres.

Processing routes: a quick overview

The two major routes for wool are worsted and woollen processing.

In the worsted system wool is first scoured to remove contaminants. Carding, in which fibres are individualised and most of the vegetable matter (VM) is removed, is followed by several drafting stages. Combing to straighten and align the fibres and remove the remaining VM and neps is followed by more drafting stages to produce the product called 'top'. This is the input to the spinner.

Tops may be spun in either dyed or undyed (ecru) form. Ecru tops may also be given a shrink-resist treatment.

More drawing follows to convert the top to roving packages, which are then spun into yarn. The singles yarn may then be twisted to form a two-fold yarn. Dyeing may also occur at the yarn stage. Weaving or knitting converts the yarn to fabric, at which stage colouration, or piece dyeing, may take place. Dyeing may also occur after the fabric is made into garments.

Wool must also be blended and scoured for processing on the woollen system. The wool input is often a blend of shorter wools, lambswool, locks, crutchings, waste or 'noil' from combing and even card wastes from worsted processing, and there can be significant amounts of VM present. Because there are no VM removal points in the woollen card, the loose wool stock may be 'carbonised', which converts the VM into brittle carbon pieces that are crushed and shaken from the wool. Carbonising may also be delayed until the wool is in fabric form.

Carding is a critical stage in the woollen process because it is here that the fibres are individualised and assembled into a full width web. At the output or delivery end of the card the web is split into a multiple number of 'slubbings', which are rolled up into packages. These are transported to the spinning frame and the yarn spun. Twisting, often into multiple ply yarns may follow depending on the end use, and the yarns will be knitted, woven or tufted into carpets.

In the woollen route dyeing may take place at loose stock, yarn or fabric stages.

Unlike the worsted route, in woollen spinning there is no combing and only limited drafting of slivers. In comparison, it is a very short route consisting of just two main processes: carding and spinning.

There is a third route, semi-worsted processing, which is intermediate between the woollen and worsted routes. Broader wool with little VM content and often in blends with synthetic fibres is manufactured into hand-knitting yarns and yarns for furnishing and upholstery fabrics. Following carding, there are several stages of gilling and the slivers are then submitted directly to the spinning frame. There is no combing process and there are no roving packages.

There are other processing routes which lead, for example, to quilt fillings and insulation batts, felts and more, but the end result is that all the wool fibres grown are used, from the lowliest daggy wool, crutchings and comb and card waste to the finest fleece wool. The woollen and worsted systems, in particular, have a synergy as discussed above, which facilitates total usage.

The woollen system in detail

The woollen spinner's craft is to create a blend of fibres that will process to a yarn and fabric having the right technical and aesthetic properties, such as loftiness or bulk, surface fuzziness, colour and colour blend – and this must all be done within a price. In spinners' recipes may be found lambswool, broken short top, noils, burr wastes, locks, crutchings, bellies, manufactured neps in a variety of colours, exotic animal fibres, bird feathers, 'pulled' rags and much more. Much of the material will be dyed. If it has two ends, a yarn can be made from it.

If required, some or all of the blend will be scoured and then, in the case of material with high vegetable matter content, carbonised. The scouring process is described later.

Carbonising relies on the differential response of wool and cellulosic material to acid attack. The stock is soaked in a solution of acid, usually sulphuric acid (5% w/v), dried at about 80^0C, and then baked at a temperature between 95^0 and 120^0 C. Passage through a pair of fluted crush rollers, and a shaker or a step cleaner ejects the finely granulated carbon pieces. Neutralising in a mild alkali solution, rinsing and drying, and often bleaching in peroxide completes the process. The aim is to avoid significantly weakening or yellowing the wool fibres while removing all VM.

It is imperative that the blend entering the process be as homogeneous as possible. Woollen lots can vary from a few hundred kilograms to tonnes, as is the case for carpet yarn. The principle of blending is the same. Horizontally layer the stock then take vertical cuts and re-layer horizontally. Often, blending bins are used and a vertical cutter, usually a spiked lattice, will move through the bin and gather and blow the stock over to a neighbouring bin to again build up a horizontal layer. At the same time processing oil is sprayed onto the blend, usually at a level of at least five per cent. This controls static generation, reduces fly waste in carding and plays a role in controlling fibre movement in drafting during spinning.

The stock is then fed to the woollen card through a weigh hopper. Modern feeding employs electronic weigh-pans, feed plates, and sometimes a device which senses the quantity of material entering the feed rollers to the card using radiation and adjusts the speed of the rollers accordingly. The aim is to optimise both short and long-term regularity in the resulting card web. While, as will be seen, the woollen card is very long, the amount of stock in the machine at any one time is only of the order of kilograms, a fraction of the total. The importance of adequate blending prior to carding is evident.

The woollen card is usually divided into two: the preliminary scribbler (or forepart) section and the final section called the carder (or finisher). Each section will typically have two main drums, or swifts. Arrayed around each will be five or six worker and stripper pairs. Tufts and, ultimately, fibres are teased apart by the pinned surfaces of the swifts and the workers and re-laid back on the swifts by the strippers. Each swift is stripped partially by 'doffers' and the fibres passed on. A high proportion, however, escapes the doffer and recycles the swift again for yet more working. The card is therefore a superb blender and leveller along its axis because of the high degree of recycling around workers and doffers and swifts. And this levelling process takes place ultimately at the individual fibre level as the density and fineness of the wire points on the cylinders increases through the machine.

It is also very important to optimise the evenness of the fibres across the card. This is achieved by the intermediate feed, which takes the sliver from the scribbler and laps it cross-wise at the feed to the carder.

After passage through the carder the fibre web is passed full width into the tape condenser. Here between a set of tapes and calender rollers the web is torn longitudinally into strips. Half the tapes proceed in an upward direction and half travel downwards, taking the strips of card web they have captured with them. Commonly both sets of tapes are divided in two again, creating four levels.

The fibre strips from each tape enter the nip of a pair of rubbing aprons, of which there are four sets, one for each level. Each set extends the full width of the condenser. As well as advancing along the card axis direction, each apron oscillates in a cross-wise direction 180^0C out of phase with its partner thus rubbing each strip into a cylindrical slubbing. The spacing between each emerging slubbing and its neighbour is four times the repetition distance of the tapes at the input to the condenser. Each slubbing is wound onto one of a set of cheese-like packages, which roll together on a constant speed drum. One bobbin of packages so formed extends across the width of the condenser. When full, the bobbins are doffed and transported to the spinning machine either manually or with the aid of automation.

Two systems of spinning are in use in the woollen sector, ring spinning and mule spinning. By far the commonest is ring spinning because of its productivity, but some spinners of fine yarn believe that mule spinning produces a superior product. Modern mule spinning machines have advanced well beyond the monsters of Dickensian times whose carriages could crush the small children used to service them, but only ring spinning will be considered here.

Slubbing from each package is unwound at the spinning frame by rolling the bobbin on a surface drum. Each slubbing then enters a draft zone, which has a false twister close to the delivery roller. This inserts twist into the slubbing upstream to the back roller. The twist arises because of the rolling action of the slubbing against the surfaces of the hollow twisting spindle, which are textured in various ways to increase the twisting efficiency. Often small lugs are used at the input to the twister to rapidly flick the slubbing. This is thought to aid the drawing of the slubbing because it mimics the flicking which occurs during mule spinning.

The delivery rollers commonly have a surface speed 30% greater than the back rollers. This attenuates the slubbing by a corresponding amount. It also has the effect of straightening the fibres and strengthening the resulting yarn. It is believed that drafting against twist in this way preferentially attenuates the thick places because the twist is unable to propagate into them as well as into the thin spots. Thusl fibres in thick spots will be able to move more freely across each other and be thinned out.

Because the slubbing at the card delivery is about 30% heavier than the yarn, the card production rate can be that much higher; a fact of no small importance given that the production rate of a woollen card at finer counts is very low.

Twist is inserted into the emerging slubbing by ring twisting. The forming yarn passes through a traveller, which is pulled rapidly round a circular ring by the yarn. The yarn is taken up onto the package and the shape of the package is controlled by the programmed vertical motion of the ring rail. Yarn tension is a function of the weight of the traveller, the friction between the traveller and the ring, and the speed of rotation. However the tension must also be sufficient to counter the tendency of the yarn to balloon. Mechanisms to collapse the balloon around the top of the spindle can be used to reduce the yarn tension. It is important that the yarn tension does not exceed the breaking strength of the weakest points in the yarn, at least not too often, in order to limit spinning breaks with the consequent loss of slubbing to waste and the introduction of a joins or piecenings in the yarn. If breaks are a problem, the speed and hence the production rate of the spinning frame will have to be reduced.

The critical nature of the carding process can now be fully appreciated. Web and hence slubbing uniformity, both short and long term, is essential to the production of quality yarn and also to the productivity and reduction in waste of the entire process. Even so, because the fibres are not generally parallel to the yarn axis and because there is a good proportion of short fibres in most woollen yarns, not all fibres contribute their share to yarn strength. Woollen yarns have a lower tenacity than worsted yarns and their uniformity for a given number of fibres in the yarn cross section is lower as well. The result is that woollen yarns rarely have fewer than 100 fibres on average in their cross-section.

Woollen yarns may be plied or twisted together and they may be knitted or woven in either singles or plied form. Means of twisting yarns together are discussed in the next section.

The worsted system

Conversion of greasy wool to top

Science takes a higher profile than art in topmaking, particularly since the development of objective measurement for raw wool. The aim is to convert an assembly of greasy wool lots in bales into combed wool or top to meet required specifications at a price. Those specifications will ultimately be governed by the yarn into which the top, often blended with other fibres, is to be spun. Blend engineering, with these two factors, specification and price in mind, is really the name of the game.

The TEAM 3 equation, which will be the benchmark from 2006, encapsulates the specification aspect.

$$H = 0.43L + 0.35S + 1.38D - 0.15M - 0.45V - 0.59CVD - 0.32CVL + 21.8$$

H = Hauteur or mean fibre length in the top

L = Staple Length

D = Fibre Diameter

M = %Midbreaks

V = Vegetable Matter Content

CVD = CV Diameter

CV = CVLength

And there are companion equations to predict the Romaine, or waste in combing, and the CV of Hauteur.

In fact, knowing the weighted objective measurements of a consignment of wool lots, all the important benchmark processing performance parameters and top properties can be calculated. Individual mills will make allowances in the use of similar equations to describe their own performance. Topmakers, whether associated with exporters or combing plants, are able to buy and assemble consignments by trading off the price against the objective measurements of sale lots. A much fuller discussion of objective measurement is available in other modules, and a good source of information is the Australian Wool Testing Authority Ltd website at http://www.awta.com.au/.

While some topmakers still blend in wool that is not tested, in order to cheapen the blend, the more rational approach is to manage the economics through specification and prediction. The ancient practice of sorting wool is no longer rational.

Consignments, in bales of greasy wool assembled for scouring, are fed to the opening line with the homogeneity of final top properties in mind. Thus, selection of input will be across sale lots. The bales are opened in a bale-breaker which is usually followed by more opening, such as double drum machines, to break the wool into approximately staple units and remove some of the dirt.

The principle of blending is the same as that discussed before and there is opportunity for mixing to take place at both greasy and scoured wool stages depending on the mill facilities. Most commonly the entire lot is blended as a unit in scoured form.

Scouring

Put simply, greasy wool is washed in a detergent solution, rinsed and dried. But of course it is not that simple. Raw wool fibre is 'contaminated' with wool wax, in both oxidised and unoxidised form by about 10%, dirt, proteinaceous and organic by about 10%, suint or water-soluble sweat salts by 5%, and vegetable matter or VM, by up to 5%. The latter is not removed in the scour but considerable R and D has been done to optimise the removal of the rest of the contaminants and to ensure that this is done in an environmentally friendly way. Only a glimpse at the process is possible here.

The opened wool is fed to the scour via a weigh belt to ensure that the feed is uniform.

Scouring takes place in a series of bowls, in modern scours each with hopper bottoms. Wool is moved through each bowl by rakes. It is very important to minimise the mechanical agitation of the wool to avoid entanglements and felting particularly as these can be set during the subsequent drying process.

The wool is maintained near the water surface by a metal perforated screen through which dirt can settle to the bottom to form sludge. At the output of each bowl the wool is moved up a drainage plate and over a breast to a set of squeeze rollers, which return most of the aqueous solution to the bowl. The temperature of each bowl and the levels of detergent and chemical assistants are carefully maintained. The level and type depends on whether the bowl has a washing or a rinsing function. Water is continually added to the scour and is moved in a counter-current fashion back through the line. Quantities of bowl liquors and settled dirt are continuously withdrawn through the hopper bottoms and contaminants are removed from these in a variety of processes. In particular the wool wax is removed in a series of centrifuges as a cream, which is refined and sold as lanolin. The remaining wastes, sludges and wastewater must be disposed of in an acceptable way.

Two significant developments in recent years are SIROSCOUR and the rationalisation of waste management. CSIRO has developed a series of modular systems for the latter which can be incorporated into a scour to suit the waste disposal regimes and environmental management demands of the local area. The complete Sirolan SWIMS system incorporated into a scour results in re-usable water, potassium-rich fertiliser and compost.

SIROSCOUR incorporates the idea of separate initial suint removal followed by two detergent and rinse cycles. The last rinse in this scheme is much more efficient at removing the difficult-to-remove contaminants such as oxidised wool grease, and there is less re-deposition of contaminants on the wool. The overall result is much cleaner scoured wool. All new scours commissioned in the last decade have been SIROSCOURS.

The scoured wool must be dried and there is a variety of drier types, such as the drum drier. The aim is to dry the wool as uniformly as possible. Wet patches are to be avoided as these lead to entanglement and excessive fibre breakage in downstream processing.

Often there will be a further opening stage after drying to remove dust. In blowing the wool to blending bins antistatic lubricant in an aqueous emulsion is sprayed on at a level of about 0.5% and the opportunity may be taken to adjust the moisture content to a regain of about 16%. Both measures minimise fibre breakage and static generation in carding.

Modern scouring is a highly technically managed process and the product is carefully monitored for moisture content or regain, residual wool wax, pH and colour.

Worsted carding

As in the woollen card, fibres are opened to the individual fibre level. Again, the card is an excellent blending machine longitudinally on the scale of a few kilograms or of the order of a kilometre in the resulting card sliver. There is no need in this case for an intermediate feed to improve cross-card evenness, although it is important to feed the card uniformly crosswise to avoid local high fibre densities on the working rollers and swift. The feed hopper will again incorporate sophisticated weighing systems to regulate the flow of fibres into the card.

The worsted card has several VM removal points, the burr beaters, which flick out VM particles, and some wool fibre, from the web of wool held on the surface of the morelle rollers. This is the source of the burr wastes which are used in woollen processing. Up to 90% of the VM is removed.

The fibres in the card sliver are only roughly aligned along the sliver axis and they will usually have hooked ends. The drawing process, called gilling, furthers the straightening and aligning of fibres. The fibres are controlled in the drafting zone by rows of pins, which move at a slightly higher speed than the back rollers. The delivery speed is about six to eight times that of the feed rollers. Thus, the leading ends of fibres entering the zone are combed to a small degree by the gill pins, and when they are withdrawn at the delivery their tails will be partially straightened.

At the input to the first gill stage after carding the moisture content of the slivers will be adjusted and an additional small quantity of lubricant may be added. It is important to maintain the moisture level in the fibres through the gilling and subsequent combing processes.

Because each gilling stage is typically fed from six to eight cans of sliver, which are then drawn into one, gilling is also a blending process. However, at each gill there will only be several percent of the total stock at any one time. A further two stages of gilling prepare the slivers for combing. Usually the first of these will have an auto-regulator which senses the incoming sliver density and corrects the draft of the gill accordingly. In this way short-term irregularities in the delivered sliver are reduced.

Combing

Combing is at the centre of the worsted route for it is here that the fibres receive their final straightening, and remaining VM, and small entanglements or neps produced in carding or developed in gilling through the tightening of structures in the slivers are removed. Above all, fibres shorter than a nominated length are removed to waste or noil. The latter, like neps, are unable to be controlled in the drafting and spinning processes that follow. The comb therefore has a huge role to play in downstream efficiency and in the quality of yarn and product. Yarns spun experimentally from top that has not been combed have a multitude of neps.

In the comb a fringe of fibres or beard gripped by the nipper jaws is pressed into the rows of pins of the rotating circular comb by the nipper brush. The rows become progressively finely pinned as the circular comb rotates. Fibres too short to be held by the nipper jaws are combed from the beard and subsequently removed from the circular comb as noil by the noil brush. The beard is raised from the circular comb, the jaws open, a shovel plate extends to support the fringe, and the finely pinned top comb is inserted down through it. At this point fibre is fed forward through the open nipper jaws by a forward motion of the feed grid. The withdrawal rollers, the lower one of which carries leather or a synthetic apron, advance through the motion of their carriage towards the fringe or beard, grasp the fibre ends and draw them through the top comb onto the apron. Fibres, neps and VM behind the top comb are trapped and will be submitted to the circular comb in the next cycle. During the withdrawal stage the feed grid is inserted into the feed slivers to ensure that fibres not gripped by the rollers do not advance. When all gripped fibres have been withdrawn, the withdrawal roller carriage retracts and the rollers then reverse so the tail of the withdrawn fibres is held in place by the suction channel. By this point the jaws have closed and the cycle is repeated.

The motion is very complicated but the result is that a set of flat, withdrawn fibre tufts is laid on top of one another to form a continuous bed. Note, however, that the position of fibres along the bed is anything but random and the bed is uneven in a regularly repetitive way. In fact, in order to once more approach the ideal of random fibre positioning, the output sliver formed by laterally collapsing the bed has to be gilled in another two stages to form top.

The amount of feed forward of the slivers can be varied and this in turn will alter the production rate. The degree of overlap of the tufts on the apron can also be varied.

More importantly, the distance of closest approach of the withdrawal rollers can also be changed, and this will alter the length of the beard and hence the maximum length of the short fibre removed by the circular comb. This setting is called the gauge. It determines the short fibre content in the top and hence its Hauteur and CVH.

The comb also has an important blending function as up to 10% of a consignment waits in the creel of the comb at any one time.

Tops are shipped to the spinner as 'bumps' or compressed packages of coiled sliver or as wound 'balls'. Prior to shipment they will be tested for a range of parameters relative to fibre length and diameter, and contaminant level including nep and VM and residual fatty matter, and the weight of the consignment will be checked and expressed in terms of a regain of 16%.

Processing costs

The market indicator for Australian wool in March 2006 hovered around A$7.50 per kilogram clean. The average price of top exported to China from Australia in 2003 was A$14.29 per kilogram. The increase in value from raw clean wool to top is therefore of the order of A$6 or so per kilogram. Included will be profit, so a guess at the underlying cost of scouring and combing might be A$2 to A$3 per kilogram. AWI has estimated the cost of combing (which would include scouring) to be A$1.75 per kilogram.

Worsted spinning

Recombing and drawing

Tops are tested on arrival at the spinner for the same parameters as before. Measurement is central to the trading relationship between combing plant and spinner.

Tops destined for weaving may be spun in undyed or ecru form, dyed or blended with other fibres, usually synthetic. Tops destined for knitting may also be shrink-proofed.

It is now common, particularly for wools finer than 21 micron, for the slivers to then be gilled and re-combed to improve later spinning performance. As in the combing plant this then necessitates two more gilling stages to restore sliver regularity.

Three or four more drawing stages follow to convert the slivers to roving. In so doing the sliver weight is reduced typically from around 20 ktex(kg/km) to around 500 ktex (gm/km) depending on the yarn count to be spun. The drafting generally is by gilling but at the roving stage apron drafting is used. As wool slivers become finer, fibre control is more effective using a pair of rubber aprons which compress the sliver under a controlled load.

At the delivery of the rover the slivers are rubbed in pairs between oscillating rubber aprons much as in the production of woollen rovings. This imparts cohesion and the 'double-mesh' roving is wound into cylindrical packages ready for spinning. Less commonly, a flyer roving frame may be used to impart a small amount of twist to a single roving via a spindle and a flyer, which have the same effect as a spindle and traveller on a ring spinner.

Conventional spinning

At the spinning frame the twin rovings are pulled off the freely suspended packages, separated, and enter the drafting zone at each spindle position. Drafting control is via two synthetic aprons driven by rollers which are recessed so that a light pressure is exerted on the drafting strand. Drafts around 20 are typical. Upon emerging from the delivery nip, twist is inserted in the same way as described earlier for woollen spinning. Because worsted yarns are generally finer, the spindles and ring diameters are smaller, and the spinning speeds are higher, up to about 15000 rpm.

The twist inserted at the worsted spinning frame is usually Z twist. Delivery speeds are of the order of 20 metres per minute.

Because of the random positioning of fibres along the yarn inherent to the process, it is impractical to spin yarns having much less than 40 fibres on average in the yarn cross-section. Worsted spinning is principally a balance between the minimum mean fibre diameter that can be used to spin a yarn of a designated count while achieving satisfactory spinning performance and yarn quality. Beyond this, the next most important parameters in order of importance are Hauteur, fibre strength, CV of diameter and, sometimes, crimp.

Winding

The yarn on the spinning bobbin is 'twist lively', which means that, if wound off the bobbin under moderate to low tension, it will tend to wind around itself and snarl. The bobbins are therefore steamed to impart temporary set.

Bobbins are then wound at high speed onto larger packages for further processing. At the winder, the ends of the yarn from the bobbins are joined automatically, commonly using a THERMOSPLICER, in which the ends to be joined are re-entangled together in a stream of hot air. This technology takes advantage of wool's thermoplastic properties.

During winding the opportunity is taken to cut out, or 'clear' thin and thick spots and neps, which are sensed by capacitive or optical sensors set to the required tolerances. Optical sensors such as SIROCLEAR can even detect dark or discoloured fibre in an ecru yarn. The ability to take advantage of detection of fault is dependent on the high quality of modern splicing as opposed to knotting which results in a fault in the yarn, which has to be mended in the fabric.

Twisting

Yarns for weaving, particularly warp yarns, are usually twisted or plied, although it is not uncommon to use singles yarns in the weft. Knitting yarns are almost invariably plied. The purpose of plying is twofold. Plied yarns are much more resistant to abrasion than a singles yarn of the same count, so they will more easily resist the torture test of weaving. Knitting yarns are plied to create a balanced yarn that is not twist lively and will not cause spirality in the resulting knitwear.

Twisting is now almost universally carried out using two-for-one twisters, which can take either two packages of singles yarn or an 'assembly wound' package which is formed by winding two yarns together. Twist is inserted by continuously looping the pair of yarns together around the package thus inserting two turns of twist for each rotation of the loop.

Plying twist is usually in the opposite direction to the singles twist, so a singles yarn of Z twist will be plied in the S direction. This has the effect of trapping fibres in the structure while increasing the yarn bulk and rendering the fibres in the singles components parallel to the yarn direction. For knitting yarns the ply twist in turns per metre will be about two thirds that of the singles twist. There are variants on this for weaving yarns and, for some fabrics, even twist-on-twist yarns may be made, where the ply twist is in the same direction as the singles. These are very hard, lean yarns of high density and are typically used in crepe fabrics.

The two-fold yarns again require steaming to give set to the new fibre configurations and kill twist liveliness.

Sirospun and Solospun

Unlike cotton, slashing or sizing the warp to enable the weaving of singles yarns is not commonly used for wool. However, wool singles yarns can survive weaving if fibres can be tucked in or trapped more effectively in the yarn during the spinning process.

Sirospun takes the two rovings from the double mesh package and feeds them, spaced apart, to one spindle position. The two separate strands emerging from the delivery nip are twisted and then converge to form the yarn. In so doing, fibres are trapped by the two-fold character of the yarn structure. The trapping is sufficient to render the yarn resistant to abrasion in weaving. Two-folding is avoided, leading to reduced cost, and fabrics can be made that are lighter in weight than those which can be produced by the conventional route using the same diameter fibres. The minimum number of fibres on average in the cross section of a Sirospun yarn is about 70 fibres.

Central to Sirospun is the 'breakout detector' which ensures that if one strand of the pair fails, the other member is broken out as well and both go to waste through suction. This prevents the production of long lengths of useless half-weight yarn.

Solospun also produces a weavable singles yarn, without two-folding, but from a single roving. The required fibre trapping is generated by the subsidiary roller which is clipped to each spinning position and which shuffles the fibre positions in the emerging strand prior to twist insertion. No break-out detector is required.

Both Sirospun and Solospun yarns are more compact than their two-fold counterparts, and the resulting fabrics are leaner. The character difference can, however, be used to advantage.

Other spinning technologies

In rotor or open-end spinning fibres are individualised by a pinned beater roller and are carried in an air stream to a high speed rotor. They are deposited and held by centrifugal force in a groove in the rim of the rotor and yarn is pulled from the groove through a withdrawal tube. Because of the forces involved it is not practical to spin yarns from wool with less than 100 or so fibres in the cross-section. Yarn can be produced at speeds up to 150 m/min however the yarns and fabrics are harsh and the application of rotor spinning for wool is limited.

Murata jet spinning and vortex spinning, MJS and MVS respectively, both produce fasciated yarn. This is yarn in which there is a central core of untwisted or parallel fibres held together by an outer sheath of fibres twisted around it. Both have found application for cotton and cotton blend yarns. The degree of fasciation is higher in the more recently developed MVS, and the yarn tenacity is higher as a result. The spinning speed is also higher, reaching 400 metres per minute. Significant reductions in spinning costs are available for cotton as a result, and in addition, fabrics manufactured from MVS yarn have higher resistance to pilling and abrasion. There are potentially large savings in spinning costs for wool. There is no significant usage at the moment for wool but more development should be valuable.

Processing costs

The production rate per conventional spindle is relatively low. Twists of about 600 turns per metre are common, so at a spindle speed of 12000 rpm, only 20 metres of yarn are produced per minute.

It has been estimated that the cost of transforming top to yarn is about three times that of combing although this is highly dependent on the yarn count and also on labour costs.

Fabrication

Knitting and weaving of wool yarns generally proceed as for any other yarns. There are however some issues specific to wool.

Weaving

The weaving process

In weaving, warp yarns are selectively opened during shedding and a length of weft yarn is inserted through the shed in the operation called picking. The newly inserted yarn, or pick, is pushed into the fell of the cloth by the beating-up action of the reed.

The shedding operation is carried out by raising and lowering of the shafts that carry the heddles through which the warp yarns pass as they are wound slowly off the warp beam and through the loom to be taken up by the cloth beam.

Because of the greater variety of weave structures that are used with wool yarns, Dobby mechanisms are most often used to achieve shedding, as they can operate a greater number of shafts than the tappet mechanism more common for simple weaves.

As pointed out earlier, wool warps are not in general sized in preparation for weaving. The yarns must therefore have the strength, extensibility, resistance to surface abrasion and minimal hairiness that will allow them to survive the multiple tension cycles and abrasive action of the oscillating reed. Thus, warp yarns will usually be two-fold. Alternatively, Sirospun or Solospun yarns can be used.

Weft insertion is achieved using a shuttle, gripper or projectile, rapier, air jet or water jet. Only the latter is unsuitable for wool because of the fibre's ability to absorb moisture. Air jet looms, which can operate at speeds up to 3000 picks per minute, are becoming the most favoured technology.

Processing costs

Weaving costs are similar to spinning – about three times the cost of topmaking. Again, costs are highly dependent on fabric weight and weave and labour cost.

Finishing of woven fabric

Loom state or greige fabric is usually lean and hard and lacking in bulk. It is the finisher's job to produce a clean fabric which has all processing additives and soiling removed. It must have the desired aesthetic qualities and it must have the required technical properties, including set and correct width for making up. Important to the finisher's craft is the knowledge of wool's chemical structure, in particular the way in which disulphide bonds may be broken and reformed to impart permanent set.

Only a thumbnail sketch of this large and important area can be given here.

Worsted fabrics will usually be crabbed by immersing the roll of fabric in boiling water. This imparts a permanent set to the flat configuration, hopefully preventing running marks and creases during subsequent processing.

The fabric is then scoured, usually in a continuous rope form, and here there may be some working of the fibre to increase yarn bulk. Lighter-weight fabrics may be scoured in open width form to maintain weave clarity and avoid any facing up. At this point the fabric may then be piece dyed.

A stenter is used to dry the fabric to the desired moisture content, with the fabric edges held under tension to the correct width by rows of moving pins. At this point the finisher may choose to shear the fabric to remove protruding surface hairs, thus adding to the clarity of appearance.

Decatising is used to further correct fabric width, and enhance aesthetic and handle properties. Fabric is wound, interleaved with a wrapper fabric, onto a perforated drum and steam is blown through from inside to outside or vice versa in a predetermined program. This may be done at high pressure and at temperatures of up to 120 degrees to impart a higher degree of permanent set. Decatising, like many of the finishing processes for wool, is generally a batch process.

Greige woollen fabric is scoured and then usually milled. The fabric in continuous rope form is cycled through a low volume of detergent solution and forced through a funnel arrangement or milling box, which results in compression of the fabric in both width and lengthwise directions. The bursting or opening up of the yarn structure, together with the differential movement of fibres across each other and between yarns, results in controlled felting, so the weave structure may all but disappear.

Drying will often be followed by raising. The fabric is passed tangentially over a drum which is clothed with metal teeth or flexible wire teeth. This breaks and raises fibres from the surface further obscuring the weave structure. Blankets are a good example of the result of raising.

Cropping or shearing may follow to control the height of the raised pile. Singeing with a flame may also be used to control the height and nature of the pile.

Woollen finishing, like woollen processing generally, is as much an art as a science and the variations and tricks are legion.

Knitting

Knitting structures and machinery

Wool is a relatively expensive fibre and this means that fully fashioned and flat bed knitting is favoured above circular knitting, where losses from cutting and sewing of fabric can be as high as 25%.

The most common structure for fine lightweight wool fabrics is stocking stitch or single jersey. (This corresponds in hand knitting to a row of plain followed by a row of purl.) The fabric is one-sided and prone to 'spirality' if the yarn is 'un-balanced' or slightly twist lively. Knitted loops will incline themselves in one direction in an attempt to relieve the torque in the yarn by attempting to ply around themselves, a less extreme example of the snarling of twist-lively yarn under low tension. Plain knitting is employed in fully-fashioned knitting machines, which, because of their gentle action, are also suitable for knitting fine count woollen spun yarns. Fully-fashioned panels have to be made up into garments.

Flat or V-bed knitting machines are very versatile because they have two beds of needles allowing stitches to be formed from each side of the fabric. Rib structures, for example, can be made (for the hand knitters a 1x1 rib would be plain, purl, plain, purl). These are two-sided, less prone to instability and fabric weights can be heavier than in plain knitting. The needle beds can be translated with respect to each other and stitches can be transferred between beds. Thus panels can be shaped, and more intricate designs like Aran knitwear can be created.

Advanced technology now enables complete garments without seams to be made on flat bed machines, at a big cost saving.

Circular knitting produces a tube of fabric that can be single jersey (plain) or double jersey (for example, interlock) in structure.

In warp knitting, yarns are presented on a beam just as in weaving and they are interlaced by sets of needles.

Circular and warp knitting are little used for wool, except for socks, which are produced on small circular machines.

Sliver knitting is a single jersey technique modified to insert tufts of combed wool into the structure. It is used to fashion artificial fleece fabric for clothing, footwear, underlays and seat covers.

Finishing of knitwear

Shetland and Lambswool are good examples of woollen spun knitwear that require finishing appropriate to the yarn structure and manufacturing route. These fabrics straight from the knitting machine can often feel a little harsh and appear somewhat unattractive.

Higher levels of processing lubricant, 5% or even more, are applied to stock before woollen carding. This must first be removed from the garments in a mild scour. Importantly, residual strains are removed from the yarn and fabric structure and this reduces the likelihood of any relaxation shrinkage taking place when the garment is first laundered by the consumer.

After rinsing, garments may often be ‘milled’. This is achieved by controlled agitation in a detergent solution, which partially releases fibres from the yarn structure allowing them to become developed as surface loops. This bursting of the yarns adds considerably to their ‘fuzziness’ and renders them bulkier and softer to the hand. Garment appearance is also improved. Following rinsing and tumble-drying the garments are pressed.

Worsted spun knitwear may also be given a mild scour but because the residual processing lubricant level is low, garments are usually dry-finished. This involves the use of a steam press with vacuum to relax the yarn and fabric strains and remove any creases. The opportunity will be taken to correct minor discrepancies in size. Milling is generally not used because the aim is to retain the clear, well-defined stitch pattern and keep any surface fuzziness or surface cover to a minimum.

Knitwear may be piece dyed and shrink-resist treated, and fibre modification treatments such as ‘soft Lustre’ may also be applied.

Processing costs

The emergence of China as the major processor of wool has greatly changed the cost structure of the fibre-to-fabric chain. This is principally because of the very low labour costs in China; the acquisition of significant quantities of the world's processing machinery at very favourable prices may also contribute. As a measure of this, Chinese worsted fabrics are typically on offer from around $US3 to $US13 per metre. Contrast this with fabrics still on offer from the traditional wool areas of the UK, which are not uncommonly quoted in excess of BP100 per yard. How the cost structure changes as China's living standards increase will be very interesting.

Given the many steps in the chain from fibre to fabric and the batch nature of many, it is not surprising that the fabric price per kilogram is many times that of the raw wool input.

Summary

The unique physical and chemical properties of wool, together with its variability within and between fibres, batches and consignments necessitates a set of processes to transform wool from fibre to fabric, which contain many elements peculiar to the fibre.

Objective measurement and testing of product through the chain has added greatly to the rational and efficient use of processes and the reduction of costs. The processes themselves have continued to be improved through the knowledge and technology resulting from research and development.

The flexibility and appeal of the products that can be made is also unique and is a major reason for wool's continuing success as a textile fibre.

References

For an excellent and much fuller discussion of the processes visit the Wool on the Web site at http://www.woolontheweb.com/LivePage.aspx?pageId=2.

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Questions

1. Blending of greasy or scoured wool is designed to do which of the following?
    a. Hide the presence of inferior wool in the consignment.
    b. Provide an opportunity to apply processing lubricant.
    c. Ensure that the properties of tops or yarns are uniform from beginning to end.
    d. Facilitate the transport of stock to the scour or the card.
2. The principal purpose of combing is to do which of the following?
    a. Straighten the fibres and remove neps, vegetable matter and short fibre.
    b. Produce noil for input to the woollen system.
    c. Randomise the position of fibres along the sliver
    d. Blend slivers together.
3. Which of the following best describes topmaking?
    a. The combined processes of scouring, carding, and combing.
    b. A preparation for semi-worsted processing.
    c. The assembling of greasy wool lots to make a consignment
    d. The packaging of combed wool lots for shipment to a spinner.
4. At which stage would you dye stock if you wished to make a check fabric?
    a. After scouring.
    b. At top stage.
    c. At yarn stage.
    d. After weaving.
5. Uniformity of slubbing across the woollen card is primarily achieved by which of the following?
    a. Rigorous blending of the input stock.
    b. Ensuring that the intermediate feed is operating correctly.
    c. Adjusting the tape condenser.
    d. Careful adjustment of the weigh-pan feed.
6. What is the purpose of inserting twist in a yarn?
    a. Increase the abrasion resistance of the yarn to facilitate weaving.
    b. Increase the uniformity of the yarn.
    c. Allow the yarn to be plied.
    d. Give strength and integrity to the yarn.