20. Value and Use of Wool

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Lecture 1: Textile properties of wool and other fibres

Learning objectives

On completion of Lecture 1 you should be able to:

- State the properties of wool that are of major textile significance
- Explain why each is important in processing and in products
- Describe the major manmade fibres that are in competition with, or complementary with, wool; their advantages and disadvantages
- Outline why and how blending is used in the textile industry (both in wool blends and combining wool with other fibres)

Key terms and concepts

Mean fibre diameter, fibre diameter distribution, coefficient of variation of diameter, price-diameter curve, hauteur, coefficient of variation of hauteur, barbe, crimp bulk and lustre, resistance to compression, vegetable matter content, medullation, manmade fibres, regenerated and synthetic fibres

Introduction to lecture 1

This lecture outlines the properties of wool and its competitor fibres that are of value in textile processing and products. Some of the definitions have already been covered in early topics but here we look at them more specifically in terms of processing outcomes.

20.1 Commercially important properties of wool

Wool has a number of physical properties that determine (a) its commercial value as a textile fibre, (b) the ease with which it can be processed into yarn, and (c) the products into which it can be converted. These properties will vary for wools obtained from different

- Parts of the body of a sheep
- Individual sheep in the same flock
- Strains of sheep within a breed
- Ages of sheep within a breed
- Breeds
- Environments (i.e. climate, terrain, pasture etc.)
- Farming properties
- Shearing regimes (timing, frequency, preparation procedures)
- Geographic regions
- Seasons of the year

This list emphasises the fact that wool is a highly variable, natural, textile fibre. The following sections outline the properties of wool that are significant for its use as a major textile fibre.

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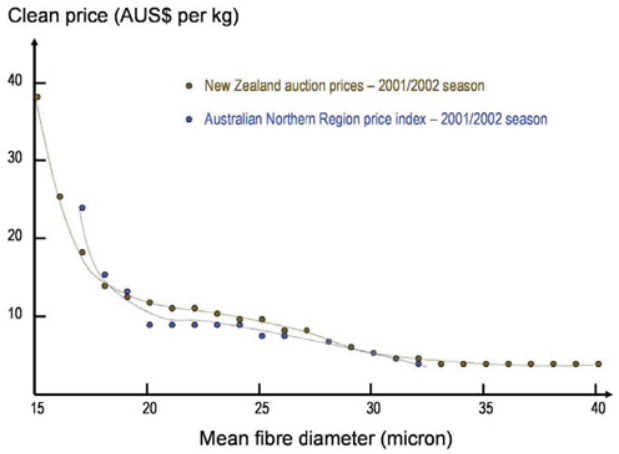
The testing of these properties will not be covered in any detail in this lecture, but a very comprehensive article on wool testing can be downloaded as a PDF file from AWTA Ltd (www.awta.com.au). This article (AWTA 2003) also includes a glossary of terms relevant to wool testing. The text by Teasdale (1995a) and the book chapter by Teasdale and Cottle (1991) are also good general references for the properties of wool and how they are measured and processed. Many of the papers presented at "Top-Tech '96" symposium are also relevant to this lecture and a selection of these papers has been provided as references. It is recommended you read these references when answering your assignment question.

The web site www.aussiesheep.com also contains useful, basic information about wool, other fibres and the Australian wool industry.

20.2 Fibre diameter

Fibre diameter is arguably the most important property of wool since it determines its suitability for certain end-uses (Teasdale 1995b). The reason for this ultimately is that lightweight fabrics desired by the consumer cannot be made from coarser wool. Finer wools produce products with a softer handle. Fibre diameter also controls the fineness to which a yarn can be spun, so finer wools are usually destined for apparel while coarser wools are better suited to carpets, outerwear and bedding. The **mean fibre diameter** determines between 70% and 80% of the price of Australian wool. The clean price versus fibre diameter data for Australian and New Zealand wools for auction lots sold in the 2001-2002 season are shown in Figure 20.1. While these curves shift with time, depending on the buoyancy of the international wool market, the shape remains more or less the same from season to season; i.e. the price rises very steeply below 20 microns and flattens off to an almost constant level above 30 microns.

Figure 20.1 Clean price versus fibre diameter for Australian and New Zealand wools in the 2002/2003 selling season.
Source: Compiled from data from Wooltrak (2002) and WoolPro (2002).

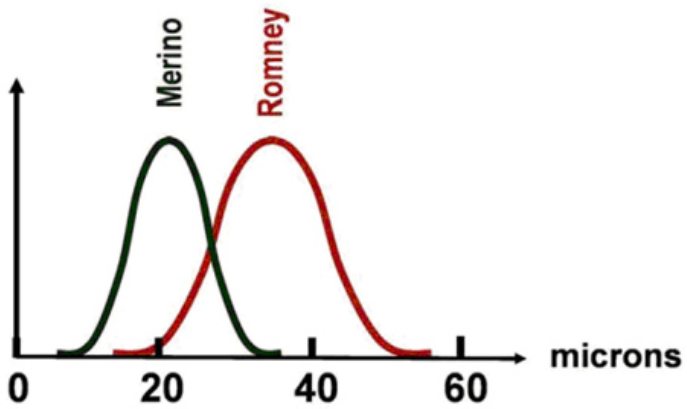


Fibre fineness affects processing performance because lower weights of finer materials can pass through the machinery in a given time. Finer wools are generally more difficult to spin than coarser wools. They are weaker (because of the smaller cross-sectional area) and are more prone to becoming entangled and forming *neps*.

The unit for fibre diameter is the **micron**, where 1 micron = 1 millionth of a metre (or one thousandth of a millimetre). The mean fibre diameter of wool in a fleece mostly depends on the breed from which it was obtained, and may range from around 16 to over 40 microns. Because of the inherent variability of wool, any sample of fibres will have a range of diameters (perhaps from 10–70 microns for individual fibres). Figure 20.2 shows the typical fibre diameter distributions for merino and crossbred wools.

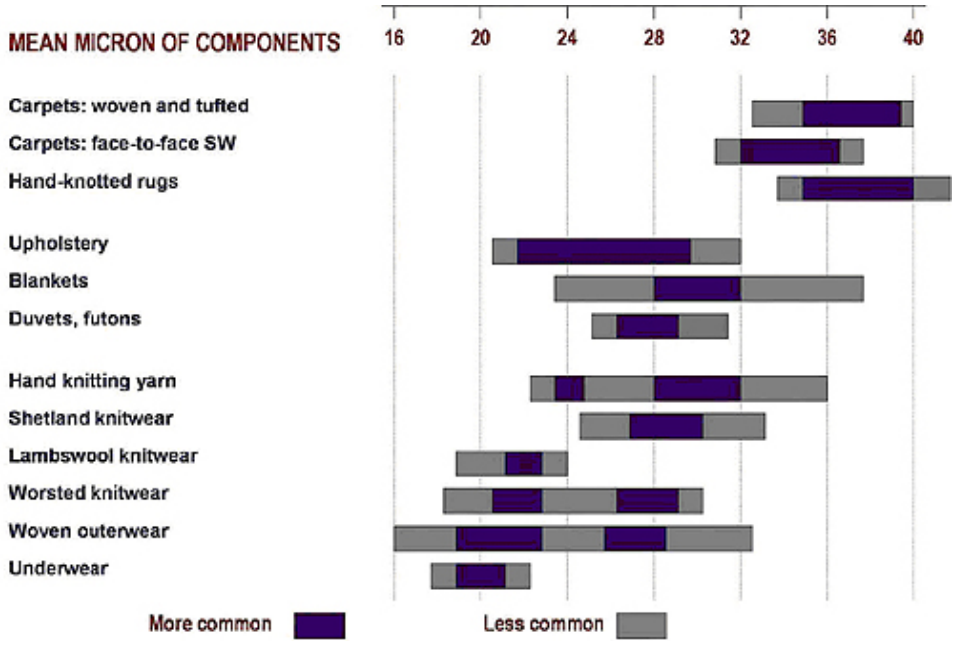
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Figure 20.2 Typical fibre diameter distributions for Merino and Romney wools. Source: Wood, (2007).



About 70% of the wool produced globally is consumed in apparel and this tends to consume the finer wools. The remaining 30%, which comprise mostly coarser wool types, is consumed mainly in carpets, upholstery and blankets. Figure 20.3 shows the fibre diameter requirements for the main products manufactured from wool.

Figure 20.3 The fibre diameter requirements for the main wool products. Source: Wood, (2007).



The **coefficient of variation of diameter CV_D**, which is determined from the fibre diameter distribution, is also important. However the actual range of CV_D in wool tops is quite limited (Lamb 1997: www.tft.csiro.au/research/pdf/wool qualityforspinners). A good approximation can be calculated using the formula $CV_D(\%) = 10.5 + 0.5 \times D$ (where D is the mean fibre diameter in microns). For wools in the range 20-24 microns about 95% of sale lots will have CV_D between 19 and 26%.

In terms of processing performance and product quality, a change in CV_D of 5% is equivalent to a change of 1 micron in mean fibre diameter (Lamb 1997). For example, a 21 micron wool with a CV_D of 20% can be a substitute for a 20 micron wool with a CV_D of 25%. The difference in spinning performance, yarn and fabric properties and next-to-skin comfort will be negligible.

While the airflow instrument has been the traditional, commercial method for measuring the mean fibre diameter of wool, it has been superseded by two modern instruments, Sirolan Laserscan and Optical Fibre Diameter Analyser (OFDA) , both of which provide the full fibre diameter distribution of a wool specimen.

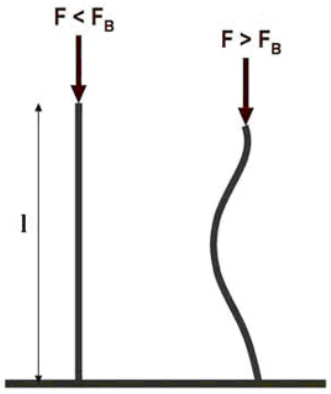
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20.3 Physics of fibre bending and its textile implications

Considering a fibre as a flexible rod, the force required to bend it varies as the square of the diameter (Wood 2000). This means that a fibre with a diameter of 40 microns requires four times the force as a 20 micron fibre to bend it to the same extent (assuming the same length of fibre is involved). The physics of fibre bending, which is governed by this simple rule, is very important in the flexibility of yarns, and the handle and drape of fabrics.

For fabric prickle the mechanism is the buckling of the fibre ends protruding from the fabric surface, which is described by Euler's theory (Naylor & Phillips 1996). (see also www.tft.csiro.au/news/pdf/skincomfort). Under compression, fibre ends remain vertical until a certain threshold force is reached, but they are unable to sustain a larger force and hence they eventually buckle (Figure 20.4).

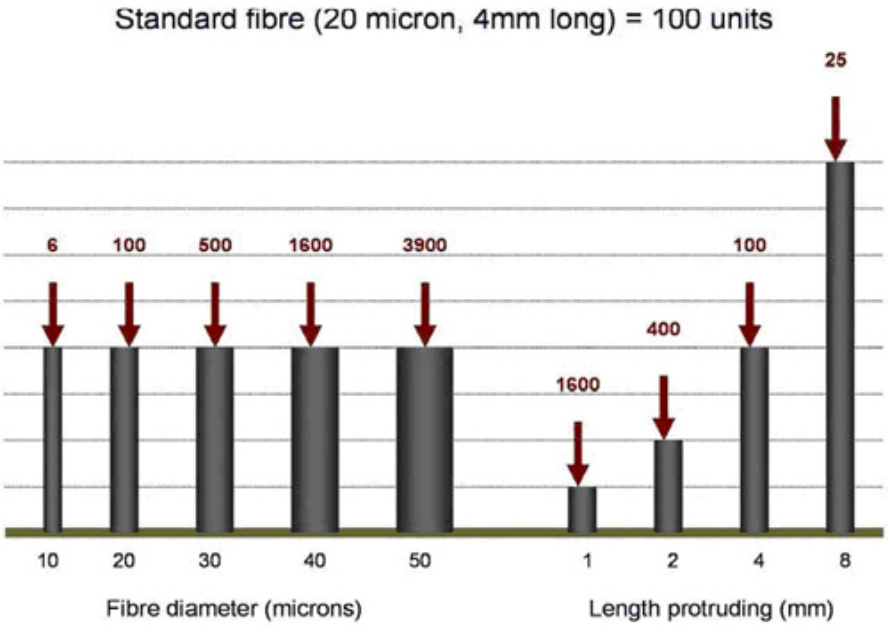
Figure 20.4 Euler's theory of buckling.
Source: Adapted from Naylor and Phillips, (1996).



Threshold force for buckling $F_B = k.E.D^4/l^2$

The threshold force at which buckling will occur is proportional to $E.D^4 / l^2$, where E is the Young's modulus (i.e. stiffness) of the fibre material, D is the fibre diameter and l is the length of the protruding fibre end. This relationship indicates that buckling is highly dependent on the fibre diameter – the coarser the diameter the higher the buckling force (Figure 20.5). However, increasing the length of the protruding fibre ends has the opposite effect - the buckling force is reduced.

Figure 20.5 Variation of buckling force with fibre diameter and length.
Source: Wood, Canesis Network Ltd (2007).



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An indicator, the so-called comfort factor (CF) has been developed for the level of prickle in fabrics: it is the percentage of fibres finer than 30 microns. A related indicator, the prickle factor (PF), is simply PF = 100% - CF The lower the CF (or the higher the PF) the greater the risk of prickle occurring, and a CF of under 95% (PF over 5%) is generally regarded as producing an uncomfortable fabric. However, fabric finishing, where surface fibres may be raised (i.e. increasing the lengths of protruding fibre ends l) or removed, can reduce prickle effects, even if the comfort factor predicts that prickle should be detectable.

For fine Merino wools the mean fibre diameter lies between 18 and 21 microns and for the risk of prickle is low. At the other extreme, in carpet wool blends, which are commonly in the 30-38 microns prickle is obviously not an issue. In fact, very coarse wools such as Scottish Blackface and Drysdale are often added to improve the blend. However in the intermediate micron range (halfbreds, Corriedale and Down breeds) of 25-30 microns variation in fibre diameter becomes a significant issue and can affect the comfort of wearers of garments made from this wool.

The other important textile aspect of fibre diameter, its effect on the spinning limit of yarns, will be discussed in the next lecture.

20.4 Fibre length and strength

While fibre diameter is the most important characteristic in fine wools, fibre length is of equal importance in coarser wools. Length largely determines the processing system on which the wool will be manufactured, and the properties of the resulting yarn (Teasdale 1995c). Rather than measuring individual fibres, the fibre length and strength of fleeces is determined by measuring the average length and strength of a representative set of staples. Commercial tests that measure the length and tensile strength (see glossary) of wool staples are available.

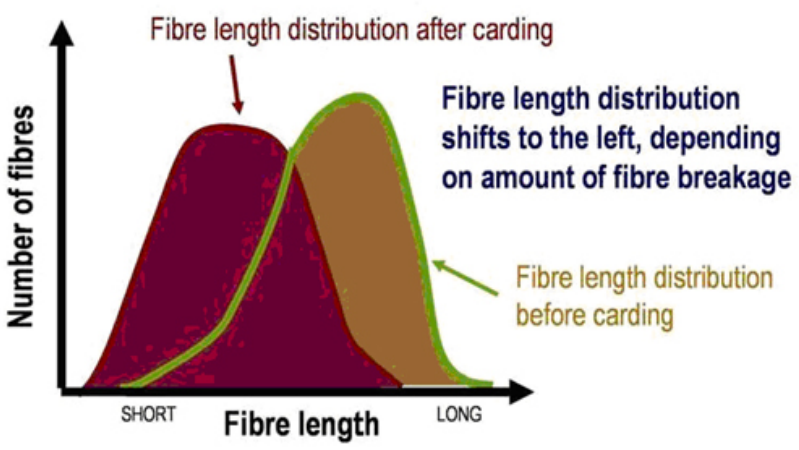
Long fibres tend to be easier to spin (e.g. give fewer stoppages) and also produce stronger and more even yarns. The presence of excessive short fibres in a yarn can lead to surface fuzzing and pilling in garments and fibre shedding from the pile of wool carpets.

Consequently wools that are short or weak (**tender** or have low tensile strength) tend to be less desirable in the market than strong (sound) wools. In practice, short wools are blended with longer wools, with the latter providing most of the cohesion required for efficient spinning and for producing a strong yarn.

In a sound wool, with no tender (or break) region, the average fibre length of the fibres when measured after straightening (i.e. removal of crimp) may be 20% longer than the staple length

Depending on their level of soundness, wools may be reduced in their average fibre length from 10% to 50% by carding, the most severe processing step (see Figure 20.6). In addition, the longer the initial fibre length the greater the fibre length reduction during processing.

Figure 20.6 Fibre breakage in carding. Source: Wood, Canesis Network Ltd (2007).



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The level of the break region in the staple, called the **position of break**, is also important. It indicates where the fibres are most likely to break when subjected to strong tensile forces, as in carding. There is a tendency for wools with breaks near the tip or butt of the staple to produce higher fibre losses, because the short fibre fragments produced by breakage will be removed by the combing process. On the other hand, wools with breaks near the middle of the staples produce tops (and yarns) with a lower mean fibre length (i.e. **hauteur**). With higher strength wools the position of break has a decreasing influence on processing performance and yarn quality.

20.5 Processing requirements

In the worsted process the removal of short fibres by combing improves the mean fibre length and quality of the yarn produced. However, the downside is the reduced processing yield that inevitably occurs from the loss of some wool from the batch. The semiworsted route, which has no combing step, requires sound, good length, vegetable matter-free wools for efficient processing and acceptable yarn quality.

The woollen processing system is more tolerant with respect to length and strength requirements. However, excessively long wools may be rejected because of the problems they give in carding.

The processed length of wool (usually in the form or a gilled and/or combed top sliver) is mostly quoted as a mean hauteur value (measured in mm). Relationships have been developed for worsted processing (the so-called TEAM formulae mentioned in Topic 17) (Couchman 1996) that enable the hauteur of a top to be predicted from the properties of the greasy wool from which it is made. The range of fibre lengths, expressed as the coefficient of variation of hauteur CV_H is also of importance in worsted processing.

CSIRO Textile and Fibre Technology have developed a computer programme, Sirolan Yarnspec (Lamb & Yang 1997), for predicting what a spinning mill should achieve when spinning a yarn using a wool top with particular properties. Among the results provided by Yarnspec is the indication that the worsted industry could use longer wools than are currently favoured. Currently it is common for limits on CV_H to be set, in the belief that an optimum value around 40-45% exists. Exceeding 45% precludes the use of longer wools in blends for worsted processing; however, it has been shown that there is little difference in yarn quality for wools over a CVH range of 30-60%. Using longer wools in blends and ignoring the effect on CV_H could result in significant reductions in processing costs (see the CSIRO article – www.tft.csiro.au/news/pdf/FA90 72.pdf).

While hauteur is the measure of fibre length used in the worsted processing industry, a related measure, **barbe**, is used in the woollen and semiworsted processing industries, especially for the specification of crossbred wools for carpet yarns. This is determined by the length after carding test, which is carried out on samples of scoured wool.

20.6 Cotting

Cotting is a serious wool fault, almost always associated with fleece tenderness. The most severe, or ‘hard’, cotts require considerable opening forces to separate the fibres and result in short fibre lengths after carding. For a cott to form there must first be a very tender region, giving short fibres in the fleece. New fibres growing in the follicles may get entangled with adjacent staples and form a matted region. At the same time, wax and suint (collectively called the *yolk*) tend to build up at the cotted region and may yellow and discolour. Cotted wools require a special opening treatment before scouring.

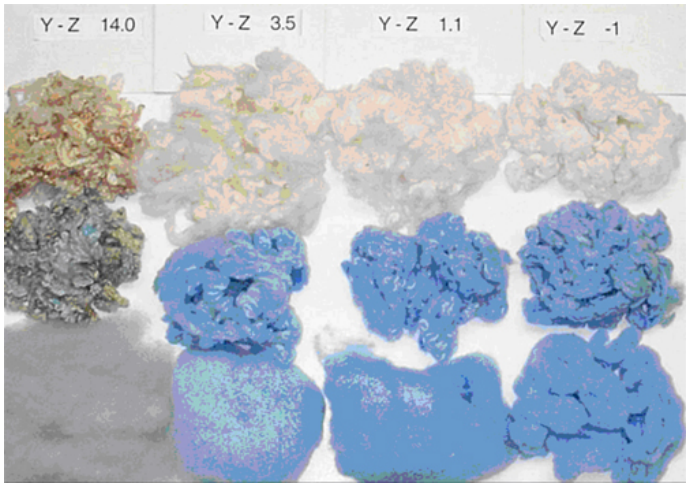
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20.7 Colour

Poor colour limits the range of shades to which a wool can be dyed, often precluding its use in products requiring light pastel shades (Teasdale 1995d). On the other hand, good colour wools can generally be dyed to any shade, and hence have a higher 'dyeing potential'. This means that a yellow wool cannot be dyed to a light blue or grey shade, for example, as illustrated in Figure 20.7. New Zealand wools vary widely in the incidence of yellowness in an otherwise basically white fibre. On the other hand Australian fine wools are well protected from yellowing during wool growth because of the dense structure of a Merino fleece.

Merino wools are normally white and bright, while crossbred types are light cream and medullated wools are chalky white. Hence colour is not the major issue in Australia that it is in New Zealand. The main colour fault in New Zealand wool is permanent yellowness. Some yellow discolourations such as diffuse yellowness, which is most apparent in late-shorn Crossbred wools grown in warm moist conditions, scour out almost completely. Others such as canary yellow, which appears after a prolonged period of wetness and warmth, are unscourable and hence are heavily discounted. A high level of discolouration often indicates the presence of microbial damage to the wool while it was a fleece. The colour is often in a band across the staple, at or below a tender or cotted zone.

Figure 20.7 Effect of wool colour on dyeing shade.
Source: Wood, Canesis Network Ltd (2007).



Naturally coloured (or pigmented) wools, which are commercially insignificant in the international wool industry, result from sheep genetics, not microbial attack. Isolated black fibres associated with some prime lamb breeds, and also stained fibres, are considered a very serious fault with apparel wools because of their visibility in a fabric, and hence their presence (even in tiny amounts) lowers the value of the wool appreciably. A top or yarn with more than 100 dark fibres per kilogram may be heavily discounted. Therefore stringent precautions are taken in sheep breeding, selection and in the shearing shed to ensure that the occasional pigmented, stained or foreign fibre does not become mixed with good wools.

20.8 Describing wool colour

The colour test measures the amount of light reflected across the visible spectrum by a prepared sample of wool (Teasdale 1995e). The *reflectance* values for the wool sample in three colour bands of the visible light spectrum: i.e. Red (X), Green (Y) and Blue (Z). This trio of measurements is referred to as the **tristimulus values**, a common term used in colour science.

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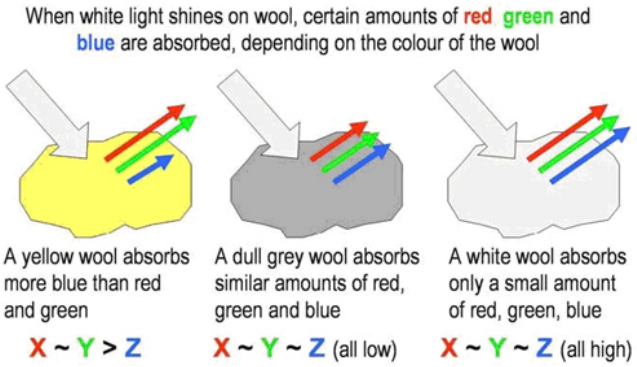
Two parameters are required to adequately specify the colour of wool. The international wool industry uses the tristimulus results as follows:

Y: measures wool 'brightness' (i.e. bright as opposed to dull/grey); the higher the better;

Y-Z: measures wool 'yellowness' (i.e. level of whiteness as opposed to creamy or yellow); the lower the better.

These parameters and the manner in which they vary with wools of different colour are illustrated in Figure 20.8.

Figure 20.8 Wool colour parameters. Source: Wood, Canesis Network Ltd (2007).



20.9 Crimp and associated properties

The crimp wave, which is most pronounced in merino wools, arises from **bilateral differentiation** in the internal cell structure of the wool fibre. Crimp is the fibre characteristic that largely determines the **bulk**, **resistance to compression** and **lustre** of wool.

The bulk of a wool is related to its crimp characteristics (i.e. the crimp spacing or **crimp frequency** and its amplitude), and measures its ability to fill space and have a springy handle. Bulk is a particularly important property in selecting wools for knitwear and machine-made carpets, where good cover is desirable in the pile. Bulk is closely associated with wool lustre (or high fibre reflectance); generally the higher the lustre the lower the bulk. For loose wool or yarns is measured by measuring the volume occupied by a sample of standard mass, when a standard (small) pressure is applied. The bulk test is mainly used to assess the suitability of wools for woollen processing into carpets and knitwear.

Resistance to compression (Teasdale 1995f) is related to bulk, although it is defined and measured differently. It is largely a function of fibre diameter can fibre crimp frequency. Increasing either of these will increase the resistance of compression. To measure resistance to compression, a sample of wool is compressed to a small, standard volume and the force that develops is measured. In comparison with bulk measurement, this is a high-compression test which is appropriate for assessing wools for worsted apparel products.

Crimp promotes cohesion between fibres so that higher bulk wools are generally easier to process. Also, because air is trapped in the spaces between crimped fibres, products made from high bulk wools tend to provide good thermal insulation and are warm. However, an increase in crimp frequency (a more closely spaced crimp wave) tends to reduce yarn strength and evenness (Lamb 1997). This is perhaps to be expected because crimp may impede smooth drafting of fibres, resulting in a more irregular (and hence weaker) yarn. There is also some evidence that wools of lower crimp frequency give fewer breakages in spinning, at least for finer wools.

Higher crimp frequency wools also give rise to a shorter mean fibre length (hauteur) in tops, and shorter tops also give poorer spinning performance and weaker, less even yarns. Thus higher crimp appears to give rise to a double penalty on spinning performance. Finally, lower crimp wools provide a discernibly smoother, leaner fabric, and a preferred softer handle.

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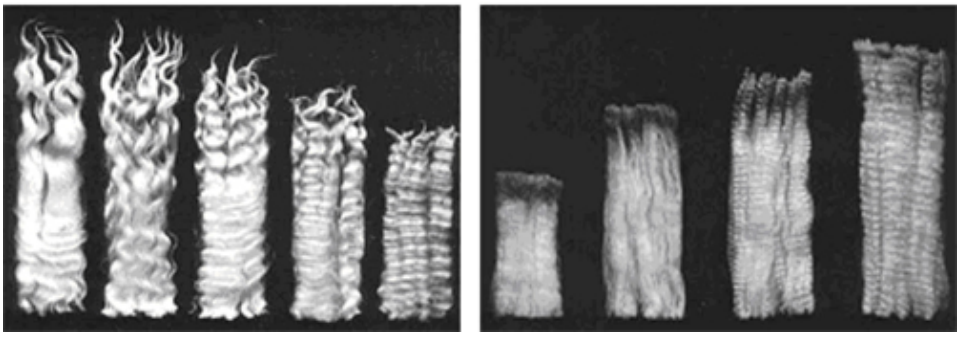
Because crimp arises from sheep genetic factors, wool bulk is closely associated with the breed. Figure 20.9 shows the staples of (a) low crimp (coarser) wools, which tend to be of low bulk (i.e. low resistance to compression), and (b) highly crimped (finer) wools that tend to have high bulk (high resistance to compression). In the latter, the crimp frequency is so high for the two left-most staples that it is difficult to reproduce their crimp in the diagram. From their very high crimp frequency it is likely that these staples have the lowest fibre diameter, and were probably produced by Merino sheep.

It is also evident from Figure 20.9 that:

a) staples of lower crimp frequency tend to have a higher level of lustre, and
b) crossbred staples tend to be tapered (or 'tippy') while fine wool staples are more rectangular, i.e. 'blocky'.

While mechanical tests have traditionally been used for the measurement of bulk and resistance to compression, fibre curvature measurement techniques using Laserscan and OFDA provide results that correlate closely with the crimp level of wool. Research on these techniques is proceeding.

Figure 20.9 Wool staples (a) of lower crimp and (b) higher crimp wools.
Source: Photograph supplied by E. Wood, Canesis Network Ltd (2007).



20.10 Vegetable matter

Vegetable matter consists of burrs, grass seeds, thistles, hard heads, straw, chaff and twigs that adhere to the fleece when the sheep is grazing (Teasdale 1995f). Some types of vegetable matter are more problematical than others, in terms of (a) the difficulty to remove them during processing and (b) their potential impact on the quality of the finished product. The presence of certain types or quantities of vegetable matter may necessitate carbonising of the wool, in which case the wool becomes downgraded in value and is only suitable for woollen processing.

The shive type of burr (e.g. wiregrass, corkscrew, etc.) possibly gives the biggest problems. They lie parallel to the wool fibres and may slip through the carding and combing machines to remain as faults in the finished fabric. On the other hand, Bathurst burrs cause minimal inconvenience because their spines fall off quite readily, allowing the burrs to fall away freely from the wool.

The amount of vegetable matter in a farm lot of wool, as well as the type of vegetable matter present, is determined as part of the IWTO yield test. Here the wool is completely dissolved in strong caustic soda solution and the cellulosic residue remaining is vegetable matter. The quantity collected is expressed as a percentage of the original sample weight.

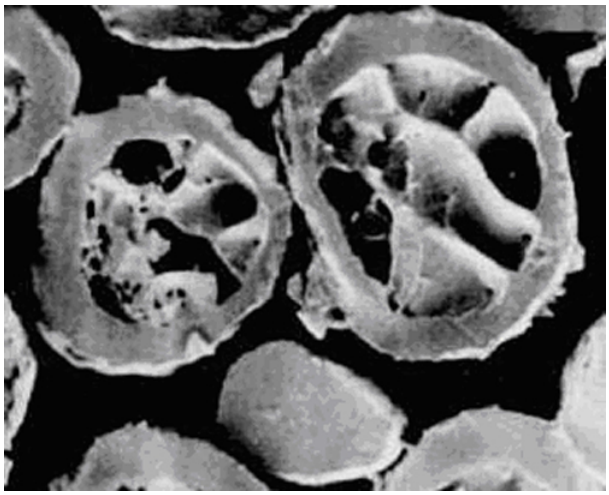
The removal of vegetable matter in processing is discussed in Lecture 2.

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20.11 Medullation

Some wool fibres are not composed of solid keratin but have hollow cells that run along their length (see Figure 20.10). This hollow zone is called the **medulla** and wools which contain a significant proportion of these fibres are said to be medullated. Such wools, which may also be termed 'hairy' or **kempy**, are coarse, harsh-handling and are brittle. Medullation in wool fibres can occur at various levels – i.e. continuous, interrupted and fragmented medullae.

Figure 20.10 Medullated wool fibres.
Source: Photograph supplied by E. Wood, Canesis Network Ltd (2007).



Medullation is generally undesirable from a processing point of view, and especially for apparel products. Because of the relatively stiff nature of medullated wool fibres, they tend to break more readily in carding (in comparison with non-medullated fibres), with their fragments being lost as waste. They do not absorb dye to the same extent as non medullated fibres and tend to produce yarn with a harsh handle and a rough hairy appearance. For these reasons, medullation has been eliminated from most sheep breeds by selective breeding over many years, and medullation is virtually absent from the Australian merino clip.

Medullated wools do have value in carpets however because of the crisp handle and unique rustic appearance that they impart to the pile. Of the New Zealand breeds, the Drysdale is the most common provider of medullated wool, while Scottish Blackface wool is often used because of its medullation content and other characteristics, which are considered to be beneficial in certain styles of carpet. Their stiffness contributes enhanced resilience, which is desirable in carpets, by increasing the force required to compress the pile and all assisting in the recovery of the pile after compression.

The degree of medullation in wool can vary, with **kemps** being the most medullated fibres. In the fleece of a crossbred sheep crutchings are more highly medullated than the main fleece and for this reason these types are also often used as a component in carpet blends.

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20.12 Ranking of wool properties

Greasy wool properties can be ranked according to their processing importance, as shown in Table 20.1.

Table 20.1 Ranking of wool properties according to their processing importance. Source: Wood, Canesis Network Ltd (2007).

Wool property	Worsted	Woollen (apparel)	Woollen (carpet)
Fibre diameter	****	****	**
Fibre length and strength	***	**	***
Colour	***	***	***
Bulk/resistance to compression	**	***	***
Vegetable matter content	***	***	**
Medullation	**	*	**

Note: **** most important *** major importance ** secondary importance * minor importance.

It is evident that the rankings depend on the process and the nature of the end product. For example, colour is very important for light pastel shade products but is much less relevant for dark shade products. Although medullation has a ** ranking for both worsted and woollen (carpet) processing, in for worsted yarn the absence of medullation is desirable while for woollen carpet yarn the presence of medullation is a mostly a benefit.

20.13 Competitor fibres

While wool is still regarded as the bench-mark in terms of quality and versatility, it faces ongoing competition in the global marketplace from other fibres, especially the high-engineered **man-made fibres**. The opportunities for engineering the wool fibre are relatively limited, although the OPTIM development of CSIRO Textile and Fibre Technology qualifies as a significant advance in wool fibre modification. Apart from this, most modifications of wool tend to be chemical in nature, e.g. to enhance the natural flame-resist, stain-resist or conductive properties of the fibre. Cotton remains by far the most widely-used natural fibre, but because of its quite different properties and uses, cotton's relationship with wool tends to be complementary rather than competitive.

Manmade fibres, which compete strongly with wool in most market segments, can be classified as either **regenerated** or **synthetic**. Rayon, the most popular regenerated fibre from wood cellulose, was developed about 1900. Synthetic fibres, which mostly originate from by-products of the petroleum industry, began to appear in the middle of the 20th century, beginning with polyamide (nylon) in 1939, polyester in 1940 and acrylic fibres in 1942. The most recent fibre to arrive on the textile scene was polypropylene in 1960.

Table 20.2 presents the characteristics of other major textile fibres. It emphasises the ability of the fibre manufacturers to deliver a wide range of special features that are difficult or impossible with a natural fibre such as wool. These features include various deniers (i.e. fibre diameters), cross-sectional shapes (such as the trilobal shape shown in Figure 20.11), artificial crimp, light scattering, soiling hiding and stain resist features.

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Figure 20.11 Trilobal cross-sectional shape of polyamide (nylon) fibres.
Source: Image supplied by E. Wood, Canesis Network Ltd (2007).

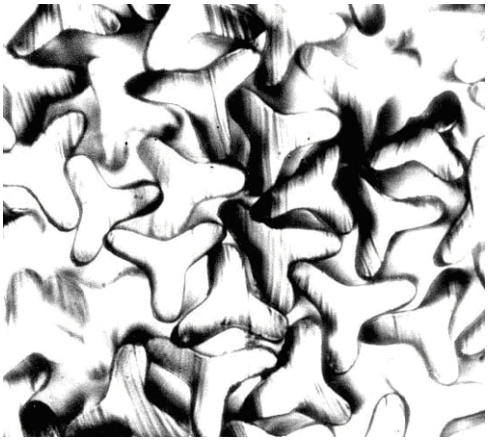


Table 20.2 Characteristics of wool and other major textile fibres.
Source: Wood, Canesis Network Ltd (2007).

Fibre	Positive features	Negative features
Wool	Highly extensible, flexible and resilient Absorbs water vapour yet water repellent Absorbed moisture eliminates static Generates heat when moisture absorbed Readily dyed Readily set by chemical treatment Resist acids and organic solvents Resists burning, ash brushes away	Relatively expensive Weaker and less abrasion resistant than most man-made fibres Dissolved by alkalis Degraded by sunlight Attacked by insects Surface scales enable entanglement and felting
Cotton (a plant fibre – pure *cellulose*, fibres are flat twisted ribbons which swell when mercerised)	Relatively cheap Strong when dry, increases when wet Good conductor of heat Readily absorbs water Not attacked by insects High resistance to organic solvents and alkalis Dyes readily with a wide variety of dyes Non-static	Relatively short fibres Not very extensible or resilient Attacked by mildew Burns easily Damaged by acids Poor abrasion resistance Fabrics crease badly if untreated Soils easily
Viscose rayon (a regenerated natural polymer, *cellulose*, with a deeply grooved surface)	Relatively inexpensive fibre Blends well with other fibres High absorbent Moderately strong Not prone to static Resists insects and mildew Good dye affinity Surface texture aids spinning	Poor elasticity and recovery Poor wet strength Creases badly, needs care when wet Poor thermal insulation, feels cold Burns readily Cannot resist strong alkalis Weakened by sunlight
Nylon (a synthetic polymer, *polyamide*; smooth fibre usually circular in cross-section and available in other cross-sections, e.g. trilobal shape)	Very strong and elastic, good recovery from deformation Excellent abrasion resistance Absorbs some water and swells little Thermoplastic, can be textured, heat-set Resists alkalis Resists insects and mildew Dries quickly, scarcely needs ironing	Prone to static unless treated Low melting point (250$_{o}$C) Melts rather than burns Damaged by acids Weakened by sunlight

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Polyester (a synthetic polymer, smooth fibres available in a wide range of cross-sections)	Very strong, and good recovery from deformation Stiffer than nylon Thermoplastic so readily heat-set to form a permanent crease Superior to nylon in resisting sunlight Heat resistant and low flammability Virtually non-absorbent Resistant to acids, alkalis, mildew, insects Low water absorption; same properties wet or dry	Prone to static unless treated Ignites and melts Lower abrasion resistance than nylon, but still good Inferior resilience to wool and nylon in carpets
Acrylic (a synthetic polymer with a slightly lumpy surface, range of cross-sections)	Relatively cheap Fairly extensible Available in high-shrink and bi-component versions to make high-bulk yarns Non-absorbent so garments dry quickly Resists staining, acids, alkalis, mildew, solvents, sunlight, weathering	Not as strong as nylon or polyester Less abrasion resistant than nylon Less receptive to heat setting than nylon and polyester Very flammable, releases toxic gases
Polypropylene (a synthetic polymer, *polyolefin*, smooth surface, wavy appearance	Available in wide range of strengths and elasticity levels Chemically inert so resists most chemicals, mildew and insects High abrasion resistance, less than nylon Low heat conduction so feels warm	Flammable, low melting point Poor recovery in carpets More difficult to dye Susceptible to soiling and oil-based stains in carpets

20.14 Textile fibre blending

Blending is done primarily to combine the best features of the different fibre components and/or to retain desirable properties at a minimum price. This may involve combining different types of wool, adding special effect materials such as neps, or blending wool with other types of fibres (both natural and manmade).

20.15 Blending of wool types

Wools reaching the market vary in value, quality and properties, with fleece wools generally being more highly valued than the various oddment types. If some latitude exists in the wool quality required for a particular product, the spinner has flexibility in blend selection. If 100% superior quality fleece wool exceeds the requirements for the product in terms of, say, length, strength or colour, some of the batch for spinning can be made up of inferior, (and hence, cheaper) types to more closely match the properties of the batch to the requirements of the process and the product. A topmaker or spinner will not want to reduce his profit by producing a top or yarn with properties that greatly exceed the specification supplied by the customer.

Combining a range of wools to form a blend for spinning is normal practice in wool carpet yarn manufacture, where the wool types can be grouped into three categories. Their proportions in the blend depend on the type of carpet for which it is intended.

1. **Mainstream wools** are used for their good colour, strength and processing performance, and their ability to 'carry' poorer quality wools. Examples of these wools are crossbred fleece and second shear body wools. Poor colour Axminster (woven carpet) blends tend to have the lowest proportion of these wools (30%) while tufted carpets generally have 40-60% depending on the pile construction and texture.

2. **Specialty carpet wools** are used for their medullation, bulk and springiness, and the contribution they make to carpet durability and resilience. Examples of these wools are Drysdale fleece and coarse Romney crutchings. The use of these wools in carpet blends varies from 10-20%.

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3. **Filler wools** are cheaper types, generally short and with poor colour, and they are included to reduce blend costs. Lower proportions of these wools should be used where light pastel shades are required. The use of these wools varies from 20% to 50%, with the highest proportions being included in Axminster carpets. In some cases recycled waste wool, such as noils from worsted combing and recovered fabric waste may be used as a cheap blend component. It is common practice in some countries to blend inferior 'local' wools with superior imported types which act as a carrier through the spinning process.

Semi-worsted carpet yarn blends require the use of good length, sound, low vegetable matter wools. For this reason the highest amounts of mainstream wools (~ 60%) tend to be used in these blends.

Blends assembled for worsted processing tend to more homogenous than carpet blends, because of the need for wools of good staple length and strength. For this reason only virgin wools are used and oddment types are mostly excluded from worsted blends. Instead, these are mostly components for blends destined for apparel via the woollen spinning route.

Blending wool with other fibres

Mostly, the blending of wool with other fibres is to utilise the respective advantages of the fibres (Roberts 1996). These advantages may relate to durability, strength, moisture absorbency and comfort, wrinkle resistance, flammability, heat resistance and chemical behaviour.

For example, a blend of 80% wool and 20% in a carpet gives better durability than a 100% wool carpet while retaining the positive attributes of wool. The following is a summary of the commonly used fibre blends which use wool:

Viyella: A registered trademark blend of about 55% wool and 45% cotton, used in light-weight apparel such as nightwear.

Wool/nylon: The inclusion of even a small percentage of nylon significantly increases the abrasion resistance of a fabric or carpet. Provided the proportion of nylon is kept below 50% the product usually looks and feels like 100% wool. The 80% wool / 20% nylon is a popular fibre combination for carpets.

Wool/polypropylene: This 50/50 combination is used to produce a cheaper carpet that to some extent retains the desirable features of wool.

Wool/polyester: This blend is suitable for 'wash-and-wear' fabrics, especially in suitings, where sharp pleats and creases are desired. These are introduced by 'heat-setting' the polyester fibres, which are thermoplastic. Usually the wool or polyester content is just over 50%.

CSIRO have developed 'Total Easy Care' garments made of wool and polyester that have outstanding shape retention, even after repeated machine washing and tumble drying cycles.

In some wool carpets around 10% of polyester fibre with a low melting point is included in the blend. This is to provide inter-fibre bonds which stabilise the yarns, hence improving the initial appearance of the carpet pile and the retention of its appearance in use.

Wool acetate and ***wool/viscose***: These blends are used to produce a fabric that appears and handles like wool but which is lower in price. The durability tends to be somewhat lower than the equivalent all-wool fabric.

Wool/elastomeric fibre: Elastomeric fibres such as Lycra have exceptional extensibility and recovery properties. Even a small amount of these fibres, say 2%, will make a significant difference to the stretch and recovery performance of a fabric.

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Lecture 2: Wool textile processing and manufacturing

Learning objectives

On completion of Lecture 2 you should be able to:

- Describe the main steps involved in converting wool into yarn
- Compare the features of the three processing routes: woollen, worsted and semiworsted
- Explain the fibre requirements for processing via these routes
- Describe the basic features and operating principles of the key machines used in these routes
- Compare the characteristics of the yarns produced by these routes
- Describe in simple terms the processes of knitting, weaving and tufting and the products manufactured by them

Key terms and concepts

Woollen, worsted, semiworsted, scouring, blending, lubrication, carding, working action, condenser, ring spinning, slubbing, sliver, roving, singles and folded yarns, gilling, drafting, combing, noils, weaving, warp, weft, knitting, tufting

Introduction to lecture 2

This lecture outlines the principle steps in converting wool into consumer products via the three main spinning routes and principle methods of wool fabric formation.

20.16 Essential steps in yarn manufacture

People have been using wool for thousands of years and while in this time the technologies for processing wool have changed greatly, many of the basic techniques have not. Along with the old techniques are old names and terms that are still in common use in the industry today.

Converting wool into yarn involves a series of processing steps, some are essential while others are optional and may be unique to a particular processing route. Three alternative routes are available for processing staple fibres such as wool into yarns:

1. The **woollen process** involves the fewest number of steps, can handle a wide range of fibre qualities and produces a relatively bulky and hairy yarn. This is the most popular route for wool carpet yarns.

2. The **worsted process** involves the largest number of steps, requires good quality wool and produces a lean, smooth yarn. Most wool apparel is produced by this route.

3. The **semiworsted route**, as its name implies, is between the two other routes in terms of number of steps and yarn features. This is a high speed process requiring long, strong fibres: widely used for synthetic fibres, but also used for wool.

Approximately 90% of Australian Merino type apparel wools are processed on the worsted system while around 80% of New Zealand wool is processed on the woollen system.

Short wools (~ 40mm), mostly blended with cotton or polyester are also processed on the cotton (short staple) system without major alterations to the machinery. While there are strong similarities with the worsted system, this processing route for cotton will not be covered here.

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This section focuses on the essential stages common to all three processing routes: (1) wool scouring, (2) fibre preparation, (3) carding and (4) spinning. The following section will focus on processes specific to particular routes.

The objectives of these essential stages are given in Table 20.3.

Table 20.3 Objectives of the four stages of converting wool into yarn.
Source: Wood, Canesis Network Ltd (2007).

Stage	Objectives
Scouring	- gentle washing action to remove grease, suint, dirt etc. to acceptably low level, with minimal fibre entanglement - deliver clean wool of consistently good colour - achieve a specified moisture regain by controlled drying - reach an appropriate pH level for subsequent dyeing - provide other treatments (e.g. bleaching) on request
Fibre preparation for spinning	- open up the clumps of scoured wool into smaller tufts - thoroughly blend the tufts of fibre - remove dust and dirt from wool - loose stock dyeing (optional) spray lubricant on fibre to assist carding and spinning
Carding	- open tufts to free individual fibres - provide opportunities for vegetable matter etc. to fall from the wool - mix fibres to form a uniform web - organise fibres in the right form for the next stage (i.e. a thin strand of fibres (slubbing), or a thick rope of fibres (sliver) - straighten fibres in sliver by gilling (worsted and semiworsted only) remove short fibres, neps and vegetable matter by combing (worsted only)
Spinning	- draft fibres to achieve a continuous strand of desired thickness - twist strand of fibres together to form a yarn - combine two or more yarns into a folded yarn by twisting scour yarn to remove processing lubricant - dye yarns in hanks or packages (optional)

20. 17 Wool scouring

Prior to yarn manufacture the wool must be scoured (Halliday 2002). **Wool scouring** is essentially a gentle, yet high production operation with the principle objective of removing all wool contaminants with minimal entanglement, at maximum efficiency and with minimum pollution of the environment. The Goulburn Wool Scour web site (http://www.gwsr.com.au) has good illustrated basic information on wool scouring and associated operations.

Figure 20.12(a) shows a view of a typical scouring line, while Figure 20.12(b) shows the surface of a scouring bowl. The general stages in a scouring plant are:

1. blending and dust removal
2. scouring (~ 3 bowls with warm water and detergent at ~ 65 ^{o}C, interspersed with pairs of squeeze rollers)

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3. rinsing (~ 2 cold bowls, and a final hot rinse bowl, interspersed with squeeze rollers)
4. drying to the required moisture **regain** in a hot air dryer
5. baling

As the wool enters each bowl it is dunked under the surface to wet it thoroughly with the liquor in that bowl. A set of rakes gently moves the wool through the liquor. When the wool reaches the far side of the bowl it is lifted up into a pair of rollers that squeeze all the liquor out of it. The wool is then dropped into the next bowl where the process is repeated. The suint (i.e. sweat) salts on the wool dissolve readily in the first bowl while the wool grease and dirt particles are steadily removed through a combination of detergent action, mechanical agitation, gravity and the squeeze roller pressure. As the wool moves through the bowls it becomes cleaner and moves into cleaner liquor.

Figure 20.12 (a) a wool scouring line; (b) surface of a scouring bowl showing the rakes in action. Source: Photograph supplied by E. Wood, Canesis Network Ltd (2007).

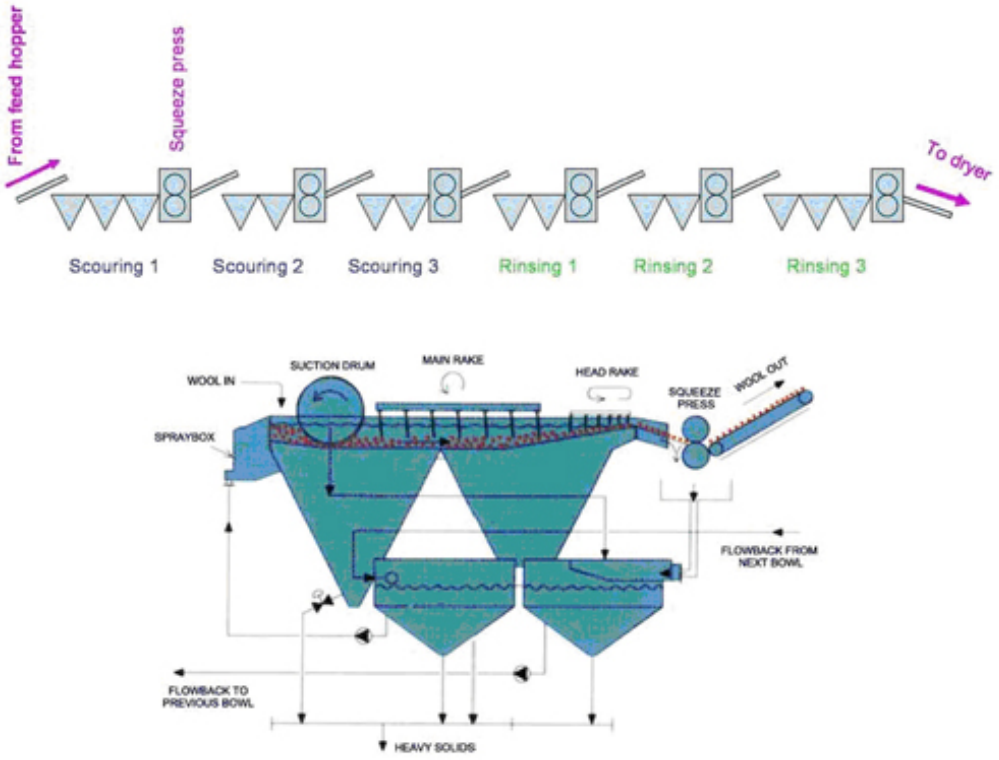




For fine wools destined for worsted processing, the retention of fibre length during carding is vital. Fine wools also have relatively high levels of grease, in comparison to coarser wools. Therefore, to minimise entanglement and facilitate grease removal a more gentle scouring treatment is required than for coarse wools destined for woollen processing. Hence, the scouring bowls for **combing wools** are often lengthened to give a longer immersion time for the wool and to deliver an acceptably low level of residual grease. Figure 20.13 shows diagrammatically the layout of a scouring line for combing wools and a single scouring bowl in the line.

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Figure 20.13 Scouring line for combing wools. Source: Andar Holdings Ltd (2007).



The scoured wool is finally packaged in dense bales ready for dispatch to a tops mill or spinning plant.

20.18 Wool blending and lubrication

In spinning plants and tops mills fibre preparation is necessary before carding (Oxtoby 1987) – the following preparation steps are usually carried out in an integrated production line:

1. Cleaning, i.e. the removal of dust and other particulate contaminants;
2. Thorough blending of the blend components to produce a homogeneous processing consignment;
3. Partial opening of the tufts of fibre to assist the subsequent carding actions;
4. Application of a processing **lubricant**.

Loose stock dyeing may occur here, especially when a large quantity of with a particular shade is required.

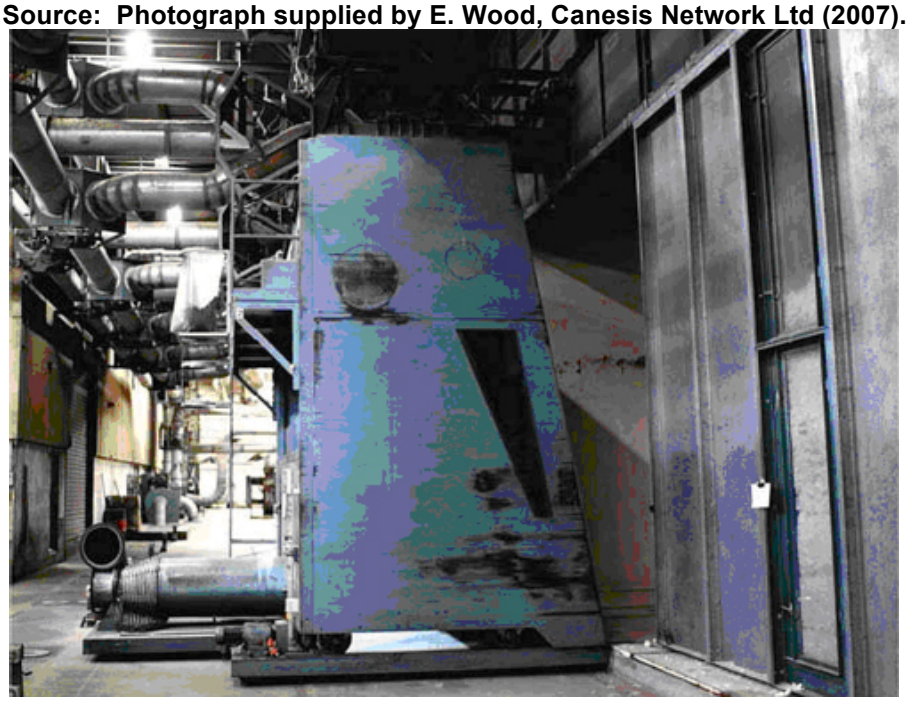
The removal of dust at an early stage in the mill carries on the task that was started in the wool scour. The extent to which blending is required depends on the processing route:

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- Woollen blends, which generally contain diverse types of wool and which are entering a processing route with few opportunities for further blending, require thorough blending at this stage. Inadequate blending causes major problems in carpet manufacture. Figure 20.14 shows the blending bin and emptier in a carpet yarn plant.

- Worsted and semiworsted blends, which are more uniform in their components and which are entering a processing route with numerous opportunities for further blending, can undergo less thorough blending at this stage.

Figure 20.14 Blending bin and emptier for carpet yarn manufacture.
Source: Photograph supplied by E. Wood, Canesis Network Ltd (2007).



Scoured wool invariably arrives at the mill in a fairly clumpy state. Feeding the wool to the card in this state would lead to excessive fibre breakage; instead an opening machine subdivides the clumps into small tufts of fibre which are more suitable for carding.

Without some form of lubrication it is virtually impossible to convert a wool fibre into a usable yarn. Lubricants (or fibre processing aids) are required for improving processing efficiency and especially to reduce fibre damage and breakage during carding and yarn spinning operations and to facilitate these processes.

Different fibre processing lubricants (specially formulated synthetic oils) are used and at different levels of application, depending on whether the yarn is to be made using the woollen processing route or worsted or semi-worsted processing routes. The woollen and semi-worsted processing routes are the principle routes used to produce carpet yarns, whereas worsted processing and some semi-worsted processing is largely used for the manufacture of finer count yarns used in apparel products.

Both the semi-worsted and woollen processing routes can involve the use of small or large amounts of lubricant, e.g. 0.8 to 3%, depending on the type of spinning process being used. In so called ‘dry spinning’ up to about 0.8% of lubricant is used but this lubricant is not scoured from the yarn after the yarn has been made. On the other hand, for conventional woollen spinning, larger amounts of lubricant (usually around 3%) are used but the yarns are scoured after spinning.

One of the most important parameters which dictates ease of processing is the regain of the wool. Lubricants are added with a similar amount of water, or additional water, to ensure that the regain of the wool is high enough so that the problems associated with static generation and flexibility of the fibre are suitably handled. If the fibre is excessively dry, i.e. the regain is low, then electrostatic problems are exacerbated so that the fibre is less easy to control, and the fibre is less flexible.

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20.19 Carding

The opened and lubricated wool is passed through a carding machine (or **card**) to be opened and mixed, and to have vegetable matter and other contaminants removed (Hunter 2002; Oxtoby 1987). A series of rotating, interacting rollers, covered with pointed wire, pins or teeth (the **clothing**), gradually separates the tufts of wool into individual fibres, to be delivered in an appropriate form to the next stage.

A card is composed of two or more of the units shown in Figure 20.15 linked in series. Each roller has a unique name (**worker, doffer, swift**, etc.), has a specific rotation speed and direction of rotation, its clothing is appropriate to its function and it is set to a close spacing to the other rollers with which it is required to interact. Types of card clothing are shown in Figure 20.16.

Figure 20.15 Single swift carding machine.
Source: Wood, Canesis Network Ltd (2007).

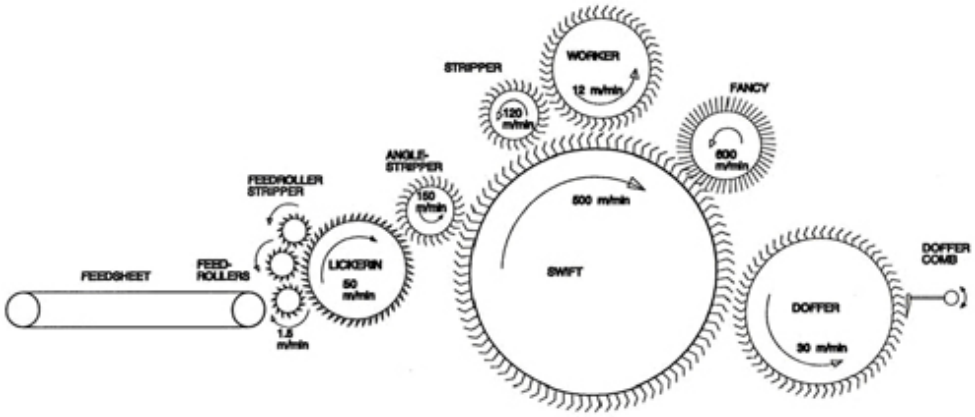
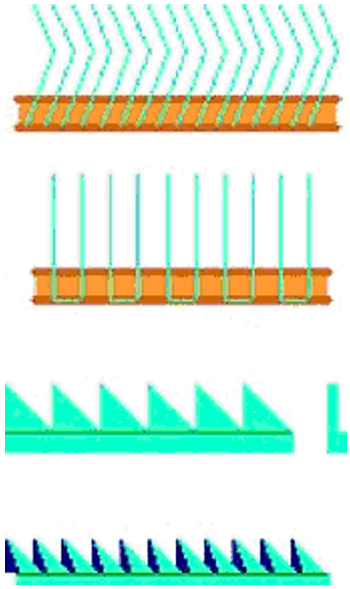


Figure 20.16 Flexible and rigid metallic card clothing.
Source: Wood, Canesis Network Ltd (2007).



In carding, part of the stream of fibres on the swift is diverted by the worker rollers, and this portion is delayed before it is returned to the main stream. By separating and merging streams of fibres at various points, a very effective blending process is obtained.

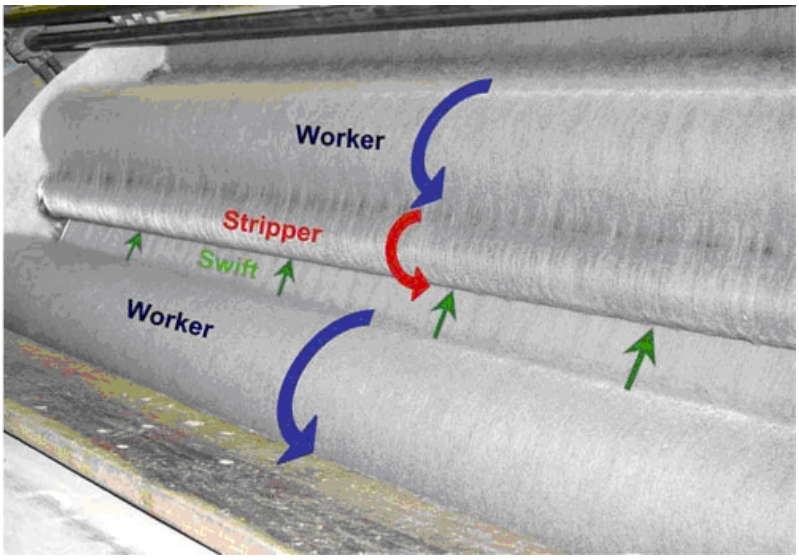
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The path of the wool through the card is as follows:

- The **feed sheet** to the feed rollers, which slowly deliver the clumps of wool to the lickerin, transports wool. The teeth of the lickerin carry out the initial opening by converting clumps into tufts and some fibres are inevitably broken at this stage
- Tufts of fibre from the lickerin are collected by the large cylinder, the swift, and cycle a number of times before (a) being caught by a worker roller, or (b) leaving the machine (or going to the next stage) via the **doffer** roller
- The worker rollers (there may be three or four of these rollers around a swift) perform the key opening and mixing functions of the card, as shown in Figure 20.17. This is where the stream of fibres through the machine is split, and later recombined on the swift via the stripper. The working action is a kind of teasing action involved the teeth of the swift and a worker roller**.**

Fibres may become embedded in the teeth of the swift clothing. The long wire bristles on the fancy raise these fibres so they are more easily caught and removed by the doffer.
The fibres are removed from the doffer in the form of a web, a continuous thin sheet of fibres. At the final doffer roller the web is either (a) channeled into a thick rope of fibres (sliver) which collects in a can, as in a worsted or semiworsted card, or (b) subdivided into thin strands (slubbing) and wound onto spools as in a woollen card.

Figure 20.17 The rollers which provide the working action on a card: workers, stripper and swift. Source: Wood, Canesis Network Ltd (2007).



The card subjects fibres to the highest tensile forces in the entire yarn-making process. If the fibres are weak for any reason (e.g. tender wool, chemically or mechanically damaged) they will have a higher probability of breakage with an elevated level of shortened fibres and short fibre fragments in the web. Typically 20-40% of fibres are broken in carding, and as much as 90% of fibre breakage that occurs in converting scoured wool into top takes place during carding. The level of fibre breakage is influenced by:

- The degree of fibre entanglement introduced in scouring,
- Fibre strength
- Fibre diameter
- Fibre crimp
- Fibre length (longer fibres have a high probability of breakage)
- Thickness of fibre layer on the swift
- Lubrication (friction) and moisture content
- Condition and settings of card (e.g. state of clothing, roller spacings)

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An additional consequence of the carding action is the formation of **neps**, tiny knots of fibre which cannot be allowed to remain for yarn quality reasons. The finer the wool, the more neps that are likely to be formed in carding. Fibre breakage in carding has negative consequences right down the processing pipeline, in terms of processing efficiency and product quality.

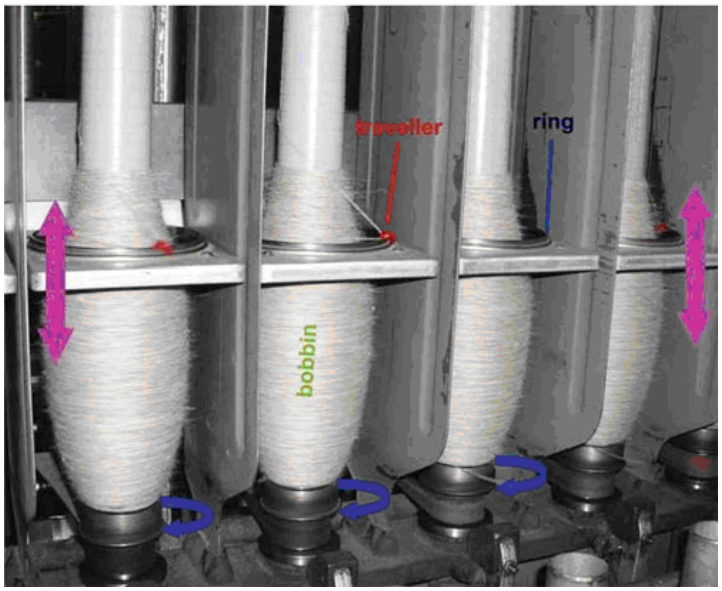
While the fibres are held by the teeth of the carding clothing, there are parts of the process where they are less well restrained, and rely on inter-fibre cohesion to be retained in the web. Short fibres and lustrous fibres are less well-restrained on the card and may fall away as waste. Carding yields are thus affected by fibre quality and characteristics. A positive effect of carding is in providing opportunities for vegetable matter to leave the flow of fibre as the tufts of wool are broken down and fibres become individualised. Obviously, wools with high levels of vegetable matter will also have poorer carding yields than cleaner wools.

20.20 Spinning

The most common type of machines for spinning wool yarns are **ring spinners** where a continuous strand of fibres is guided onto a **bobbin** which is mounted on a **spindle** rotating at high speed (5000-13,000 rpm) (Hunter 2002; Oxtoby 1987). The popularity of ring spinning is because of its versatility in terms of yarn linear density (or count) and fibre time; also the superior quality and character of the yarn it produces.

This action inserts twist into the strand to form a yarn (Figure 20.18). A typical ring spinning frame consists of a hundred or more such spindles.

Figure 20.18 Spindles of a ring spinning machine.
Source: Wood, Canesis Network Ltd (2007).



An important part of the mechanism is the **traveller**, a small plastic or metal clip mounted on a circular ring to guide the yarn onto the bobbin. The rotation of the bobbin causes the traveller to cycle rapidly around the 'ring' at speeds of up to 40 metres per second, lagging a little behind the bobbin. The speed of the traveller limits the productivity of ring frames, because of excessive wear and heat generated at high speeds. The ring (mounted on its ring rail) oscillates slowly up and down to enable a tidy, compact package to gradually form on the bobbin.

The original strand (e.g. slubbing) relies mostly on inter-fibre friction for its strength. If the fibres are straight (i.e. lustrous) and/or too short the strength of the strand may be insufficient for it to withstand the spinning forces and it breaks. Too frequent end breaks are the major cause of poor spinning performance.

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It is common practice to twist two (or more) singles yarns together to form a stronger, and more even two-fold yarn. This operation, which is often carried out on a machine very similar to a ring spinner, is called **twisting**. In a two-fold yarn the fibres are better secured within the yarn structure and hence have improved abrasion resistance. Also, by twisting two yarns of different colour together, different texture effects can be achieved in fabrics and carpets.

In general the most important properties of yarns are its **tenacity** (strength), **elongation** and **evenness**. Depending on the type of yarn, its bulk, and hairiness may also be relevant. (See the reading, Canesis Network Ltd. 2003b).

20.21 Colouration of wool yarn

Wool dyes easily (Parton 2002). It will absorb a wide range of dyes from pastel colours to the deepest shades. However, wool colour influences the range of shades to which it can be dyed. For example it is impossibly to produce a light blue or grey shade with a yellow wool.

Dyes are normally applied to wool in a water solution. Heat is important in the process and wool is usually dyed at or near boiling point. Colour may be added to the fibre by dyeing at several alternative stages in wool yarn manufacture:

a) Loose stock dyeing
This method of dyeing the fibre is carried out before blending, and is most suited where a large quantity of yarn of the same colour is required. Because of the blending that is carried out subsequently, it is relatively easy to get uniformity of colour and good colour match to the specification.
Because some weakening of the fibre occurs, loose stock dyeing tends not to be used when retention of fibre length in carding is of major importance, i.e. in the worsted process.

b) Top dyeing
The dyeing of the intermediate product, a top, is only carried out in worsted yarn manufacture

c) Hank dyeing
Hanks of yarn may be dyed, especially when relatively small quantities of one shade are required, e.g. for highly patterned woven carpets. This method places more importance on accurate colour matching than loose stock dyeing.

d) Package dyeing
Finished yarn wound on cones or other type of packages may be dyed in a large vessel.
Alternatively, undyed yarn is converted into a fabric or carpet that may be dyed by various methods of piece dyeing – winch dyeing, jet printing, etc..

20.22 The three processing routes

The three routes for making a wool yarn have been mentioned briefly, and their common features outlined. These routes will now be compared with respect to the raw material requirements, the machinery used and the characteristic of the yarns produced.
Table 20.4 summarises the main features of the woollen, worsted and semiworsted systems.

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Table 20.4 Main features of the three processing systems.
Source: Wood, Canesis Network Ltd (2007).

	Woollen	***Semi-worsted***	***Worsted***
Wool requirements:	• can handle all wool types, but more suitable for shorter wools rather than very long; VM should not be too high	• wools should be sound, staple length 75-125mm, and with low vegetable matter content	• requires wools which for their diameter are longer, better style and sounder
	• usually a wide range of blend components	• usually a limited range of components in blend	• uses similar wools rather than a mixture of types
	• all fibre diameters used, from very fine to very coarse	• mainly medium fineness wools; 27 - 35 µm	• mainly fine wools; less than 30 µm, usually less than 24 µm
	• can use reprocessed wools of all types	• not suitable for short reprocessed wools	• wastes never used in blend
	• blend cost generally lowest because oddments and recycled fibre can be used	• blend cost higher than woollen because predominantly fleece wools used	• blend cost highest
Complexity of the processing system	• the shortest route with fewest steps, large woollen card has low production rate	• a compact, high production system, cheaper to operate than worsted system	• the most complex route; largest number of steps; card similar to semi-worsted card
	• card removes some vegetable matter but cannot tolerate high levels	• limited ability to remove vegetable matter and short fibres; card removes some	• vegetable matter and short fibres removed by combing; card removes some
	• carding is very critical because it sets the yarn count, and is the final opportunity for blending	• carding is less critical because of substantial blending and drafting in subsequent steps	• carding is less critical because of substantial blending and drafting opportunities in subsequent steps
Properties of yarn:	• minimal alignment of fibres, many may be hooked	• reasonable degree of fibre alignment	• fibre alignment very high, giving the most even yarn
	• yarn is hairy - many fibre ends protrude from surface	• less fibre ends and loops protrude from surface	• few fibre ends and loops protrude, so least hairy
	• yarn is bulky, soft and resilient	• medium bulk and resilience	• low bulk, and firm handle
	• tends to be weakest with breaking strength of 3-5 g/tex	• typical breaking strength 5-7 g/tex	• tends to be strongest yarn; breaking strength 7-9 g/tex
	• require at least around 120 fibres in yarn cross-section	• require at least around 75 fibres in yarn cross-section	• require at least around 40 fibres in yarn cross-section
End product uses:	• suitable for all purposes: apparel, carpets, furnishings.	• carpets and knitwear mainly	• high quality weaving and knitting yarns for quality apparel
	• yarn structure often not apparent in finished product	• yarn structure may or may not be clearly visible	• yarn structure is usually well-defined in product

20.23 Woollen processing system

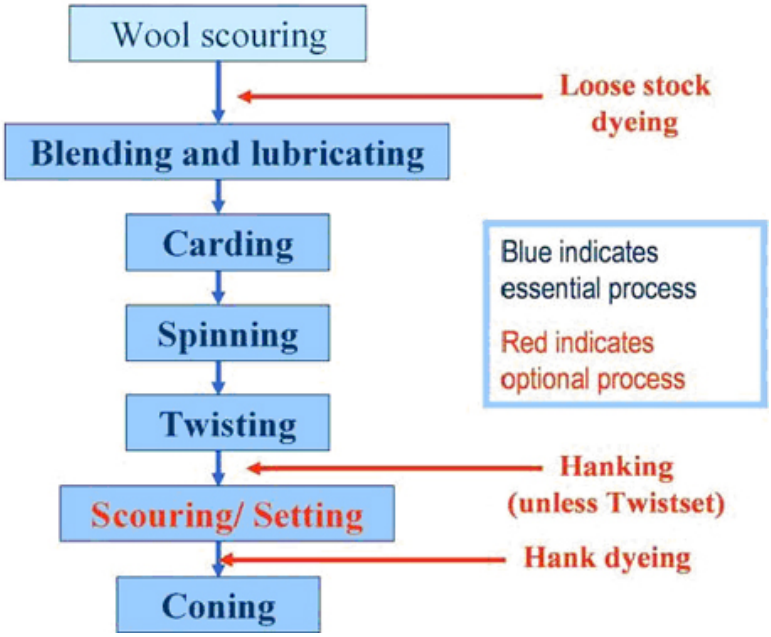
The steps in the **woollen system** are shown in Figure 20.19.

The raw material requirements for the woollen system are summarised in Table 20.4.

The woollen system is the simplest and most versatile of the three yarn manufacturing routes, and tends to be used to process blends of wools which vary in length and fibre diameter. The system is capable of handling the poorer-style wools and the short and tender wools. Shorter, inferior quality fine wools for apparel (i.e. carding wools) are processed on the woollen system, as well as most coarse wool blends destined for carpets.

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Figure 20.19 Steps in the woollen system.
Source: Wood, Canesis Network Ltd (2007).



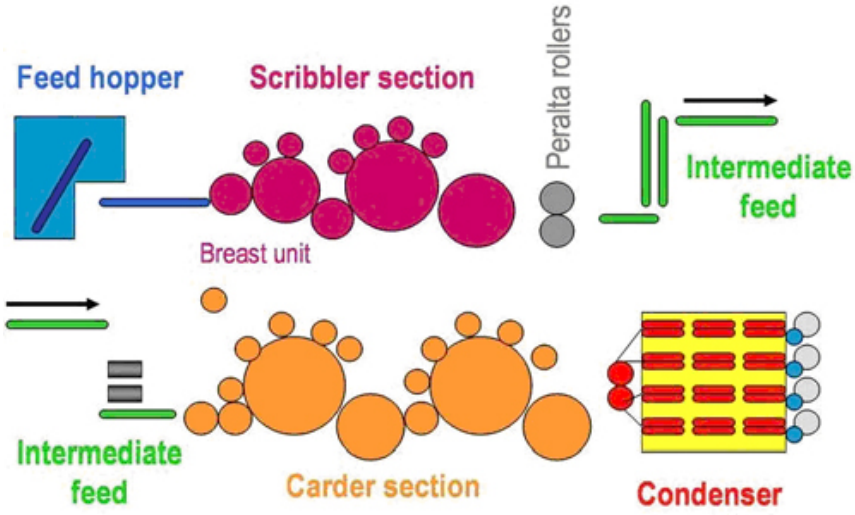
Worldwide, virgin wool represents a relatively low proportion of the total fibres processed on the woollen system. The majority of fibres processed comprise noils, re-cycled and recovered wools, man-made fibres and cotton. The woollen system can handle natural and man-made fibres of almost any type, fineness and length 'provided it has two ends'. In the case of wool, the woollen system handles wools as fine as 19 microns or as coarse as 40 microns and wools ranging from 25 to 80 mm in length. Woollen carding generally requires quite a low level of vegetable matter because removal systems are inefficient; wools high in vegetable matter require **carbonising** first.

Woollen carding

The main parts of a woollen card are shown in Figure 20.20 (Hunter 2002; Oxtoby 1987).

From the feed hopper the wool generally passes through two carding stages (termed the **scribbler** and **carder** parts respectively) to ensure a thorough, gradual opening of the wool tufts and the mixing of fibres and the formation of a thin web of carded fibres. A **web-purifier** (or **Peralta**) is a pair of smooth steel rollers that apply high pressure to crush the vegetable matter into fragments, hence making them more easily removed from the web.

Figure 20.20 Main parts of a woollen card.
Source: Compiled from Hunter (2002) and Oxtoby (1987).



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The **intermediate feed** (or Scotch feed), a conveyor which links the two parts of the machine, delivers the web to the carder part by a cross-lapping action that facilitates good side-to-side blending. At the **tape condenser**, the **web** is separated into narrow strips and consolidated by a rubbing action into a thin, continuous ribbon called **slubbing**. Figure 20.21 shows the spools of slubbing produced by the condenser.

Figure 20.21 Condenser of woollen card showing the spools.
Source: Photograph supplied by E. Wood, Canesis Network Ltd (2007).

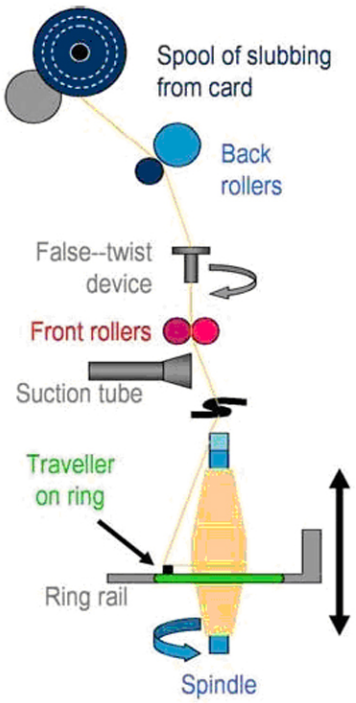


A woollen card is a more complicated machine than a worsted card because it provides the final opportunity for fibre mixing, and it also determines the count (or thickness) of the yarn. Any variations or irregularities in the slubbing it produces persist through spinning and hence may affect the quality of the finished yarn. Hence a highly accurate feed system to the card is essential. A woollen card may be up to 3.5 metres wide and 15 metres or more in length.

Woollen spinning

Figure 20.22 shows the main parts of one spindle of a woollen ring spinning frame (Hunter 2002; Oxtoby 1987).

Figure 20.22 Spindle of a woollen spinning frame.
Source: Compiled from Hunter (2002) and Oxtoby (1987).



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Because the blends used for woollen yarn are relatively short, they are not suited to **roller drafting** (as used in worsted and semiworsted processing to convert a sliver into a finer strand of fibres). Slubbings, which are composed of relatively short, poorly aligned fibres do not draft as well as longer, well-aligned fibres, hence the front rollers rotate only about 20-30% faster than the back rollers (i.e. a draft of 1.2-1.3) to avoid excessive end breaks.

The false twist device inserts a temporary twist in the slubbing to give it sufficient strength to withstand the stresses of spinning and also reduces strand irregularity. The suction tube extracts slubbing from end-breaks and delivers it to a receptacle. This waste can be recycled back to the card hopper.

Other steps

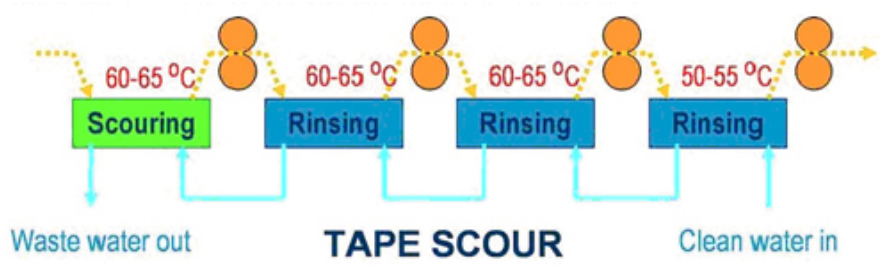
Yarn scouring

In conventional woollen spinning around 3% of processing lubricant, an emulsion of oil with water with water, is sprayed on the wool before carding. (This rate of application significantly higher than for worsted and semiworsted spinning where around 0.3% is common.) The lubrication treatment has three purposes:

1. the moisture content of the wool fibres is increased, making them more extensible, hence more resistant to the stresses of carding, and also reduces electrostatic effects which make the fibres difficult to control.
2. it reduces the friction between fibres, and between fibre and the card teeth, thereby reducing fibre breakage in carding; 3) web cohesion is improved and so fewer fibres (especially the shorter ones) are lost as droppings or fly.

To avoid downstream problems such as excessive soiling of the yarn or rapid soiling of carpets in use, the processing lubricant must be removed from the yarn in a process that is similar to wool scouring. Figure 20.23 shows a diagram of a yarn scouring machine. At the same time as yarn scouring occurs, for yarns destined for cut-pile carpets, one bowl will contain the chemicals required for a **setting** treatment that enables the yarn to resist untwisting when cut. Insect-resist agents can also be applied to the wool during this process.

Figure 20.23 Tape scouring machine for woollen yarn.
Source: Wood, Canesis Network Ltd (2007).



Yarn twisting

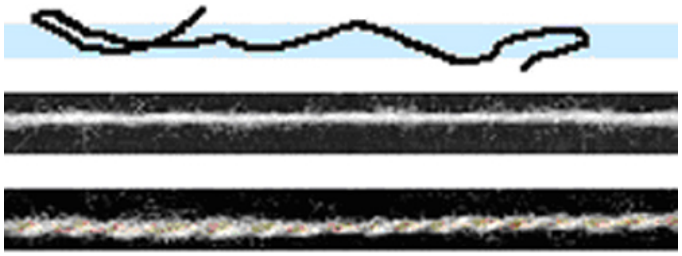
To provide sufficient strength and improve the uniformity of woollen yarns, and reduce the tendency to untwist, two or more singles yarns produced are usually twisted together to form a *folded* or *plied* yarn. Two-ply yarns are the most common for carpets. It is usual to ply worsted and semiworsted yarns too.

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Characteristics of woollen spun yarn

A woollen-spun yarn is characterised by a high proportion of short fibres distributed very much at random throughout the yarn. Longer fibres often undergo reversals in direction and may protrude from the yarn, to contribute to a hairy and quite irregular appearance. Figure 20.24 shows a diagram of a typical fibre path in this type of yarn, a singles yarn and a two-fold yarn.

Figure 20.24 Woollen yarns.
Source: Wood, Canesis Network Ltd (2007).



The loops and ends of fibres protruding from the surface have an important influence on the tactile and visual properties of a woollen-spun yarn. A fibre with reversals contributes less to the strength of a yarn than if it was fully extended without reversals, as it would be in a worsted yarn. Therefore, woollen yarns tend to have less strength than worsted yarns, and to obtain sufficient strength for spinning a minimum of over 100 fibres is required in the cross-section. The yarns tend to be of a coarse **count** (i.e. thicker than worsted yarns), spun to a low twist, and hence are bulky, soft handling, relatively hairy, and less regular than worsted yarns. The reversals and other irregularities in the paths of the fibres within the yarn create air spaces, which also contribute to the soft, bulky handle of woollen-spun yarns (provided the twist level is not high).

In the main, woollen spun yarns are used in woven, knitted and tufted products; i.e. carpets, blankets, tweeds and heavier woven and knitted apparel.

20.24 Worsted processing system

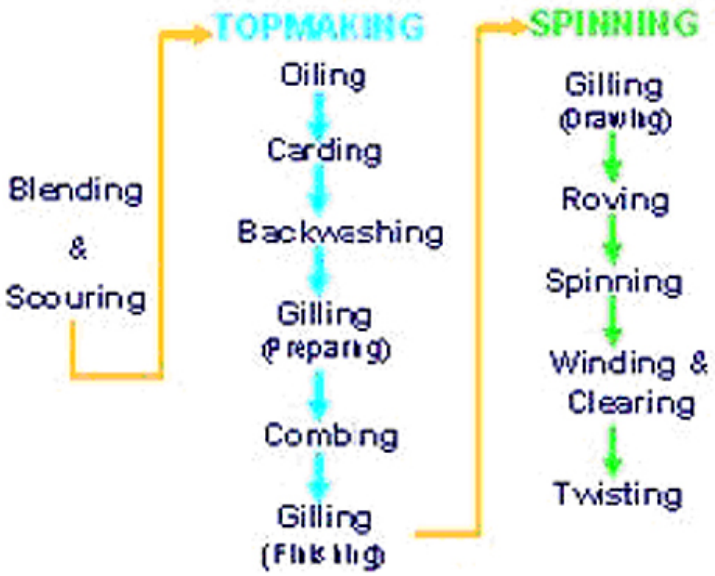
The worsted system has the most steps, and better-style, long sound wools are required to ensure efficient processing and acceptable yarn quality. A diagram of the system is shown in Figure 20.25. The sequence of fibrous structures in the worsted system is:

scoured wool – card sliver – gilled sliver – top – roving – singles yarn – folded yarn

Generally only virgin wool, typically ranging in length from 40 -100 mm is used in worsted processing. Some vegetable matter can be tolerated because the combing step will remove any fragments remaining after carding. Fine and medium wools are favoured to produce a fine, flexible yarn and ultimately a light, soft-handling fabric.

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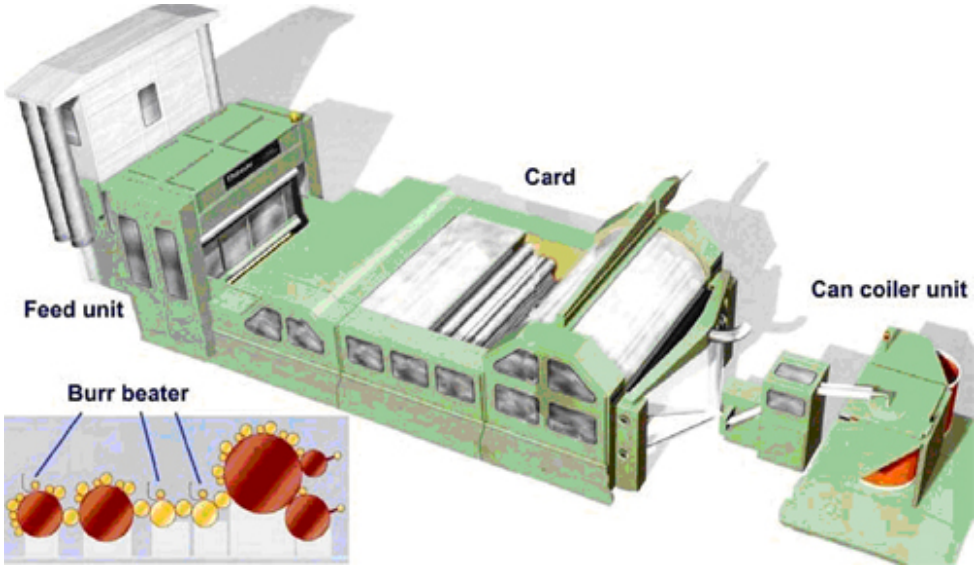
Figure 20.25 Worsted processing route.
Source: Wood, Canesis Network Ltd (2007).



Carding

A worsted card (Figure 20.26) is a somewhat simpler, more compact machine than a woollen card because (1) there is less reliance on it to provide thorough fibre blending, and (2) a condenser section is not required because the wool is removed in the form of a **sliver** (Hunter 2002; Oxtoby 1987).

Figure 20.26 Worsted card.
Source: Compiled from Hunter (2002) and Oxtoby (1987).



The diagram shows three sets of **burr beaters**; a brush that ejects vegetable matter from the flat topped teeth of a **Morel roller**, while the wool fibres are carried on past the ejection point.

After carding the subsequent steps in **topmaking** are **gilling** and **combing** (see Harrowfield 1987).

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Productivity in worsted carding

Three options are available to increasing the carding speed:

1. Feed the fibre at a higher rate This increases the level of fibre breakage and hence is not feasible
2. Make a wider carding machine There is a limit to the width to which a carding machine can be manufactured. Engineering problems increase when the width exceeds around 3 metres
3. Run the machine faster In woollen carding, the overall machine speed is governed by the speed of the condenser section. A worsted card does not have this section and in principle could be operated at a higher speed. However, it has been thought that this will also increase fibre breakage.

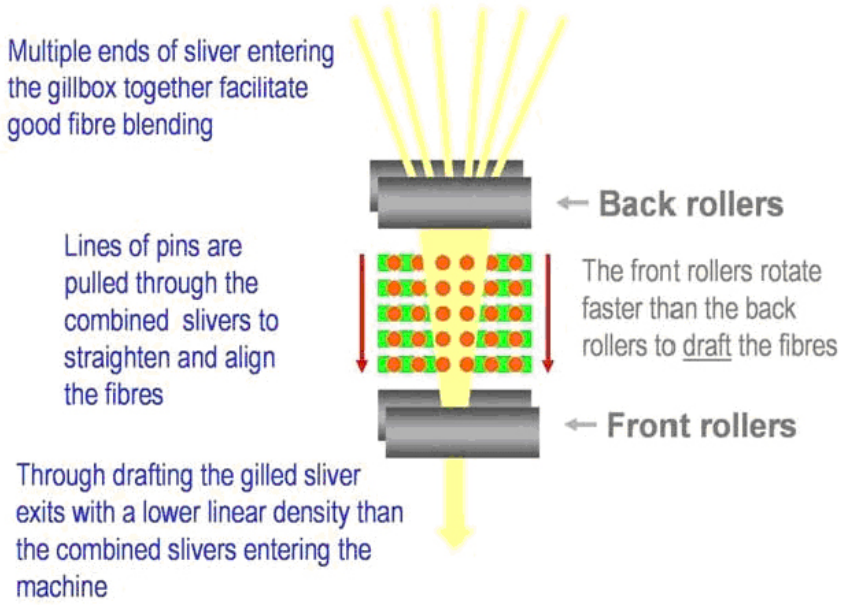
Research at CSIRO demonstrated that a high speed card was feasible and led to the release of a commercial model by NSC. On this card (2.5m wide) typical production rates of 220 kg/hr for 22 micron wool and 160 kg/hr for 19.5 micron wool are being achieved. Overall, the increase in production speed was achieved by:

- Increase in swift speed and diameter
- Increase in number of carding points (worker rollers)
- Optimising speed ratios between different rollers
- Improved vegetable matter removal
- Double doffer
- Efficient suction system to keep environment clean.

Gilling

The card sliver is passed through a series of perhaps three **gilling** steps to straighten and align fibres in a neat, parallel arrangement (Hunter 2002; Oxtoby 1987). Figure 20.27 shows the parts of a **gillbox.**

Figure 20.27 Principles of gilling.
Source: Wood, Canesis Network Ltd (2007).



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The operations carried out by a gillbox are:

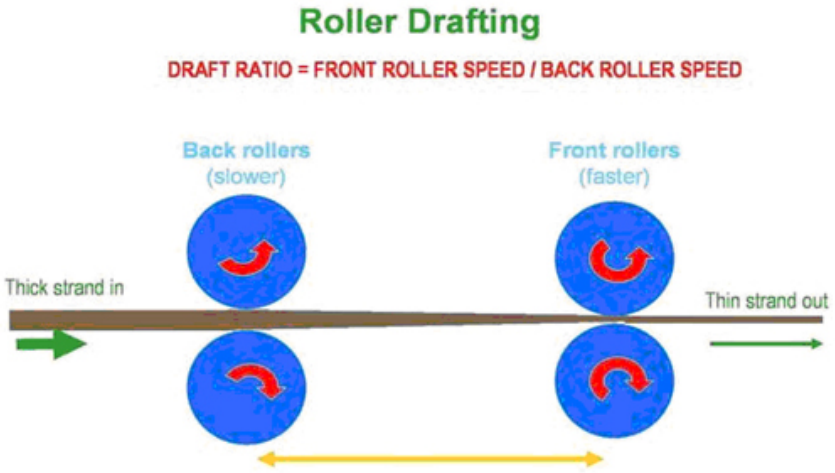
1. **Fibre alignment**
   The removal of fibre hooks introduced in carding, and improvement of fibre parallelisation and alignment, is achieved by drawing lines of steel pins through the sliver as it passes through the machine.

2. **Drafting**
   This reduces by controlled fibre slippage the thickness or **linear density** of the sliver and is achieved by two pairs of rollers (Figure 20.28). The front rollers rotate faster than the back rollers (perhaps 5-15 times; i.e. giving a draft ratio of 5-15) so that sliver leaving the machine is much thinner than the combined thickness of all slivers entering the machine.

3. **Blending**
   This is achieved by feeding a number of ends (perhaps 6-10) in parallel into the gillbox.

Several gillings may be carried out in succession in order to make the fibres in the sliver as straight and parallel as possible.

Figure 20.28 Principle of the drafting operation.
Source: Wood, Canesis Network Ltd (2007).



Combing and drawing

Combing enables finer, stronger, more uniform and less hairy yarns to be spun at better efficiency (Hunter 2002; Oxtoby 1987). The gilled sliver is combed to remove **noils** (i.e. short fibres), **neps** (tiny clumps of fibre) and fragments of vegetable matter, then it is gilled again to restore the parallel alignment to form a *top*. In the worsted system the first group of processes, i.e. carding, gilling and combing is called **topmaking**.

Fibres shorter than about 20-30 mm are removed while more than 95% of neps and vegetable matter are generally removed. The hauteur of the sliver may be increased by 10-15%.

The most commonly used comb is the rectilinear comb – also known as the French comb, continental comb or dry comb. While this (and other combs) are complex machines, what they do is fairly simple:

1. The comb has a rotating cylinder that has a section with fine pins set very close together – approximately 25 per centimetre. Slivers of wool (typically 24-32 ends) are fed into the comb through a gill box and protrude across a plate above the comb.

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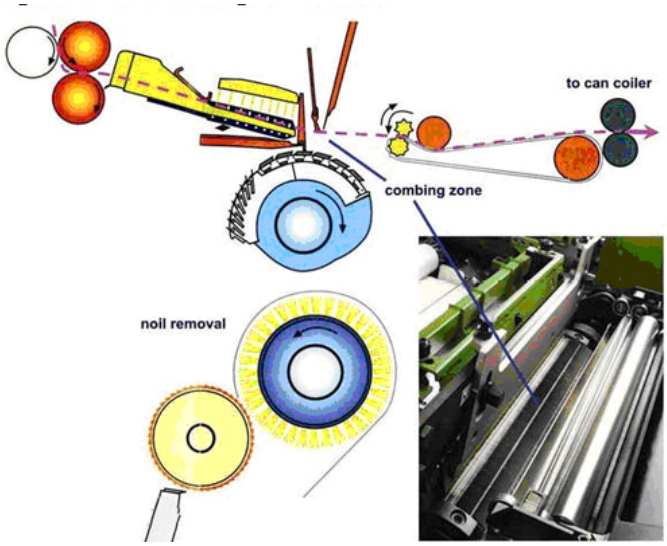
2. The slivers are clamped down firmly, and the cylinder rotates, bringing the comb around to comb the loose ends of the protruding fringe of fibres.
3. A drawing-off roller unit then comes across to grab onto the combed ends and draw them through an intersector comb.
4. The combed wool is then reconstituted back into the form, of a top, which is fed into another can.
5. While this is happening, the comb section keeps rotating around to a small brush, called a noil brush, that brushes the short bits of fibre (i.e. noils) held in the comb into another can under the machine. If there was vegetable matter in the wool, this will have been combed out of the wool and will be brushed off the comb section along with the noils.

Noils are generally re-used in woollen yarn manufacture, where fibre length is not so critical. While noils have some value, they are heavily discounted from the value of the top (about 40% of the value); hence the topmaker strives to minimise these losses by

a) using wools of appropriate quality, especially with respect to length, strength and VM content
b) setting the machines to minimise fibre breakage and nep formation.

Fibre breakage in combing can range from around 17-30%.
For high quality worsted yarns, a top may be re-combed to ensure that the material supplied for spinning is of superior quality, even though this additional step involves significant extra expense.

Figure 20.29 Combing mechanism.
Source: Wood, Canesis Network Ltd (2007).



Backwashing is the process of treating wool slivers and tops in an aqueous detergent solution to remove any unwanted impurities such as residual grease and lubricants and also to straighten fibres (i.e. reduce fibre crimp). A gilling step follows. Backwashing can either precede or following the combing process.

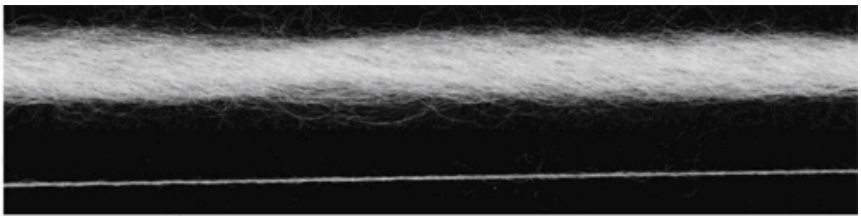
Re-combing is carried out after top dyeing when fibre blends are involved or when producing high quality tops, to improve subsequent spinning and weaving efficiencies.

After topmaking, the top is drafted (i.e. drawn out to reduce the thickness) to form a thin ribbon of fibres, or **roving**, before being twisted and further drafted in spinning to form a yarn. In the process of producing a worsted yarn, the wool goes through a number of intermediate stages. A top may have 25,000 fibres in its cross-section while a worsted yarn may be required to have only 100 fibres or less, depending on the **linear density** that is specified. To achieve the required yarn fineness, a considerable reduction in the thickness (or linear density) of the fibrous structures must occur, through successive drafting at each stage (which also improves fibre alignment). In high draft worsted spinning system, the differences in roller rotation speed may be as high as 1:200.

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Efficient drafting requires a good fibre length – too many short fibres not held by either pair of rollers (i.e. uncontrolled 'floating' fibres) will result in an uneven product. For this reason minimal drafting is used in the woollen system, and longer, sound fibres are required for worsted and semiworsted spinning. Additional rollers (or **aprons**) in the drafting zone can assist in controlling the passage of the shorter fibres. As a result of (i) the removal of short fibres in combing, (ii) the parallel arrangement of the fibres presented for spinning and (iii) the high degree of twist imposed, a worsted yarn is sufficiently strong to require a minimum of only 40 fibres in the cross-section. Hence very fine, even, firm yarns with satisfactory strength can be spun on the worsted system (Figure 20.31 shows a roving and a worsted yarn).

Figure 20.30 Roving and worsted yarn.
Source: Wood, Canesis Network Ltd.



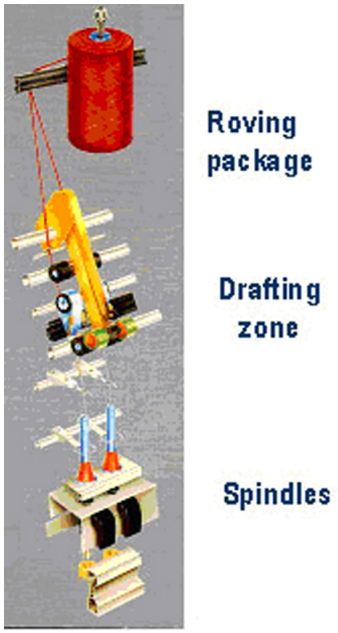
Worsted spinning

A worsted spinning frame is similar to a woollen ring frame (Hunter 2002; Oxtoby 1987): but with two essential differences

1. Pairs of front and back rollers running at very different speeds perform drafting on the roving. An apron is usually included to control the movement of fibres in the drafting zone. Otherwise, the fibres may be delivered in bunches for spinning and an uneven yarn results.
2. Because the yarns are invariably much finer than woollen yarns, the components (spindles, travelers, rings, bobbins) are of smaller dimensions.

Figure 20.31 shows a pair of spindles on a worsted ring spinning frame.

Figure 20.31 Worsted spinning. Source: Wood, Canesis Network Ltd (2007).



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Solospun

The Solospun attachment is a pair of grooved rollers that is clipped to the drafting arms of the worsted spinning frame (Prins, Lamb & Finn 2001). The rollers split the fibre ribbon emerging from the front rollers and do not permit the twist to reach the gripping (or nip) of these rollers. Instead, substrands of fibres are allowed to twist and recombine in such a way as to increase the localised twist (cohesion) and compactness of the yarn, as well as fibre integration into the yarn. As a consequence, the tensile strength and abrasion resistance of the yarn is increased. Compared to two-fold yarns, yarn production costs can be reduced by up to 50%. (see also Weaving)

Spinning limits

There are practical limitations concerning the minimum number of fibres required in the cross-section in order to successfully spin a yarn. When the number of fibres is below this minimum, there is a risk that an excessive number of end breaks will occur during spinning as the strand of fibres being twisted has insufficient cohesion to withstand the stresses of spinning.

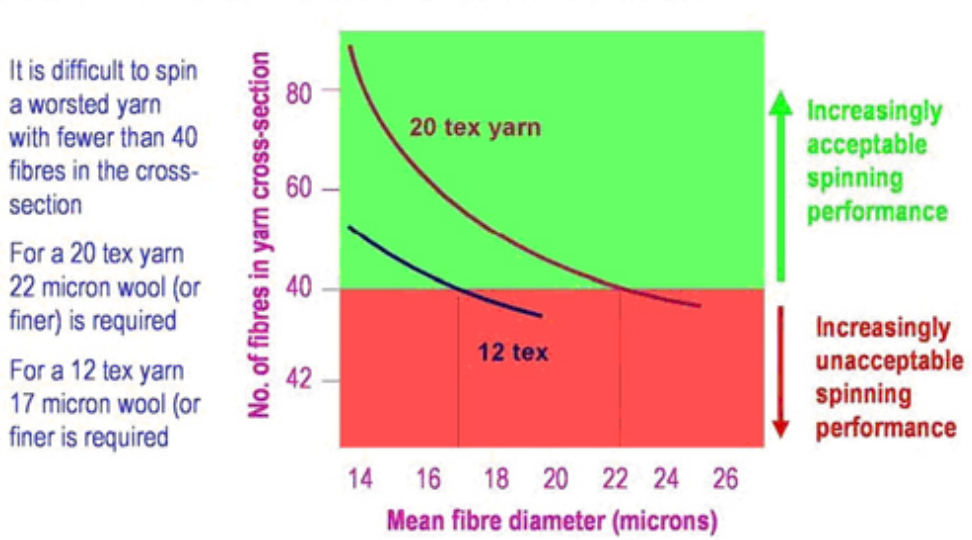
It is generally accepted that for worsted spinning, the minimum number of fibres is around 40, while for semiworsted yarns it is close to 75 fibres. For woollen-spun yarns the minimum number is much higher, i.e. around 120 fibres, reflecting the inferior fibre organisation in these yarns. These numbers are often called the 'spinning limits' for these types of yarn.

Consequently to spin a very fine yarn, fine fibres are essential. Figure 20.32 illustrates the situation for worsted spinning. To produce a 20 tex yarn with the minimum required number of fibres in the cross-section, wool with a mean fibre diameter of 22 microns or less is required. For a 12 tex yarn, the upper limit to the mean fibre diameter is 17 microns.

The finest yarn count that can be spun from wools of a particular mean fibre diameter (MFD) can be calculated from this formula:

Minimum count (tex) = 0.00103 x MFD^2 x N
where N = minimum number of fibres in cross-section
(worsted: 40; semiworsted: 75; woollen: 120)

Figure 20.32 Limiting yarn counts in worsted spinning.
Source: Wood, Canesis Network Ltd (2007).



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20.25 Semiworsted processing system

Semi-worsted processing machinery is mostly used to process synthetic fibres (Hunter 2002; Oxtoby 1987). The semi-worsted system was developed to produce a yarn with greater strength than in the woollen system, but without the expense of removing short fibres in a combing step. Wool is passed through a high-production card (similar in construction to a worsted card), gilled several times to straighten the fibres, and spun directly into yarn from a thin sliver using a spinning frame with high draft (draft ratio up to 40).

Because of the need for superior fibre length for the high drafts often employed in spinning, the semi-worsted system requires sound wools, preferably of 100120 mm staple length (with a minimum length of at least 70mm). Because there is less opportunity for the removal of contaminants, the wools selected for this route must be free of vegetable matter.

Semi-worsted yarns are intermediate in properties between those produced on the worsted and woollen systems. They are used mainly for manufacturing carpets, hand-knitting yarns and machine-made knitwear. Because of the greater fibre length and the degree of straightening by the gilling step, semi-worsted yarns tend to be less bulky than woollen yarns (i.e. relatively 'lean'). Hence bulkier wools need to be included in the blend if good fabric cover or a softer handle is required in products.

The level of processing lubricant applied before carding (typically 0.3%) is sufficiently low that no yarn scouring operation is required. This is a further saving in this high production processing route.

Fabric formation

After yarn manufacture the next step towards the end-product is fabric formation. This will generally involve one of the following processes, depending on the type of product:

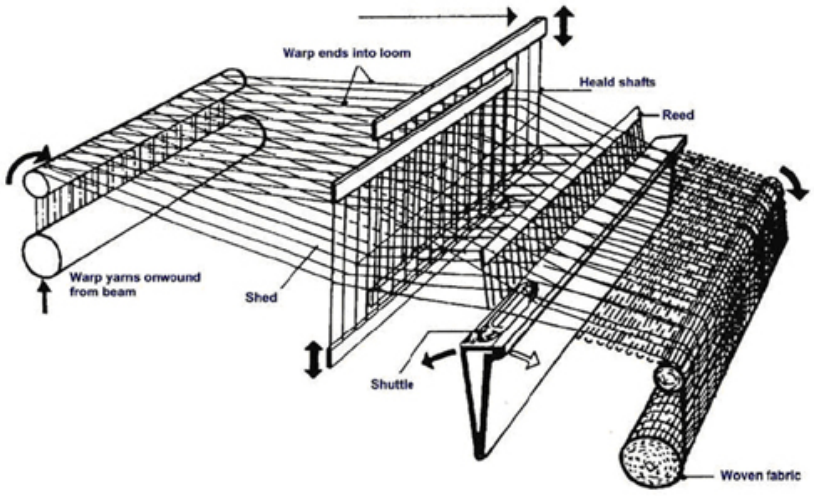
1. Weaving
2. Knitting
3. Tufting

Another method of fabric formation, nonwovens manufacture, omits the spinning stage and goes directly from a card web to consolidating and stabilising the fabric. This, and methods of fabric formation which are less relevant to wool, will not be covered here.

Weaving

A simple weaving loom is shown in Figure 20.33 (Russell et al. 2002; Crawshaw 2002).

Figure 20.33 a simple loom.
Source: Compiled from Russell et al. (2002) and Crawshaw (2002).



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Flat woven fabrics are constructed from two sets of threads that cross at right angles. The threads that extend throughout the length of the fabric are termed **warp** threads and those which cross the width are termed **weft** threads. To form a fabric, warp threads are raised or lowered according to the required weaving pattern and the weft threads pass through the opening or shed thus formed. As the shed closes before the next weft insertion, the last weft thread is pushed or 'beaten up' close to the previous weft thread in order to form a compact structure. Although Figure 20.34 shows a shuttle as the means of passing the weft threads through the shed, in modern looms metal rods (or rapiers) or air or water jets are the main methods of weft insertion.

Thus is a weaving cycle there are three basic operations:

1. Shedding – forming an opening between the warp threads
2. Weft insertion – inserting weft threads through the warp shed
3. Beat-up – compacting the weft threads to form a closer structure

In modern looms, the pattern is introduced by electronic control of the motion of the **heald** frames, which in turn determine which warp threads are raised and which are lowered when each shed is formed.

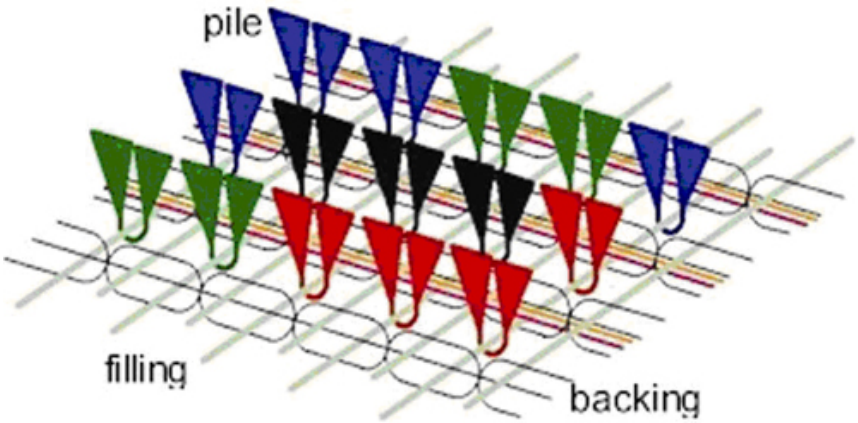
At each crossing of the yarns in the fabric there are only two possibilities; either the warp passes over the weft or under the weft. This provides opportunities for different patterns of interlacing to be produced. Each weave pattern produces fabric of distinctive appearance and properties.

The warp threads are subjected to abrasive forces, while the weft threads must withstand tensile forces in weaving. Therefore, yarn quality is important to ensure good weaving efficiency and acceptable fabric quality. While it is usual to use two-fold yarns and/or to apply size to warp threads, the Solospun attachment to a ring spinning frame enables a singles yarn with acceptable abrasion resistance for the weaving of light-weight fabrics to be produced (PDF file on Solospun).

Various **finishing** processes after weaving may remove surface fibre ends, raise fibres from the fabric surface, or give the fibre improved dimensional stability. The fabric is then ready for making into garments. A woven fabric is characterised by a firm handle and limited stretchiness in the warp and weft directions

As well as apparel fabrics, the weaving process is used to make carpets, in particular the Axminster, Wilton and face-to-face types. While the methods of manufacture are quite different, all involve the formation of a woven base cloth, in which the pile yarns are integrated to give a cut pile and/or a loop pile surface. Very complicated weave structure and intricate carpet designs are possible with modern looms. Figure 20.34 shows the structure of a woven carpet.

Figure 20.34 Structure of a woven carpet.
Source: Wood, Canesis Network Ltd (2007).

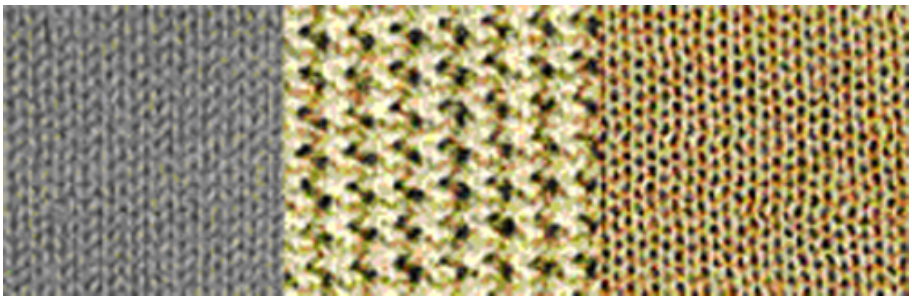


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Knitting

The main alternative to fabric formation for apparel is knitting (Russell et al. 2002). Machine-knitted fabrics are made by linking loops of yarn using a series of hooks. Figure 20.35 shows some typical knitted structures.

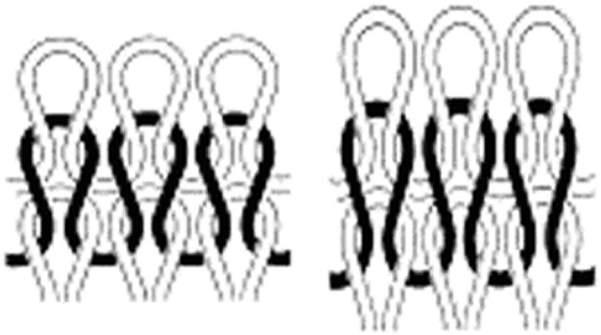
Figure 20.35 Knitted structures.
Source: Wood, Canesis Network Ltd (2007).



Knitwear can use worsted, semiworsted and woollen yarns. The first two types of yarn are mostly used for fine, machine-made knitwear. Woollen-spun yarns tend to have a higher bulk and springy handle than the other types, and thus are best suited to heavy, bulky garments which trap air and thus provide excellent warmth. For semiworsted yarns for knitwear, bulky wool types are included in the blend to compensate for the lean firm yarn normally produced via this route.

In comparison with woven fabrics, knitted fabrics are much more extensible in all directions than woven fabrics. They can be stretched easily, simply by distorting the shape of the individual loops, as shown in Figure 20.36. When a knitted garment is stretched it tends to return to its original size and shape as soon as the tension is released. It is possible to stretch a wool garment to change its area by a considerable amount. On the other hand, it is not possible to increase the area of a piece of woven cloth very much by stretching it. This is because a stretch in one direction is accompanied by a contraction in the perpendicular direction.

Figure 20.36 Stretching of a knitted fabric.
Source: Wood, Canesis Network Ltd (2007).



These differences is stretching behaviour explain the differences in their formfitting capabilities. Garments made from woven fabrics require accurate tailoring to provide a good fit to the shape of the body. However, they will generally retain their shape well in use and in cleaning. Knitted garments, by contrast, allow a greater tolerance in size and shape and are wrinkle resistant. Because of the greater stretch they allow, the wearer has more freedom of movement, particularly in close-fitting garments. Because of their more porous construction, moisture permeability is higher with knitted fabrics, but they are not as effective as woven fabrics at providing insulation in windy conditions.

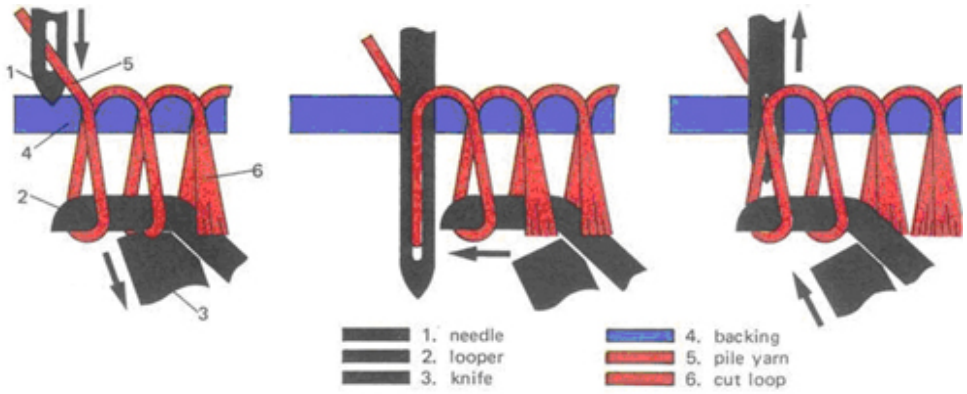
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Tufting

Wool carpet manufacture has had a long and proud history (Crawshaw 2002). The tufting process, which is a relatively new technology, is now the dominant method of making carpets, including wool and wool-rich products. A tufting machine resembles the action of a sewing machine, but with a line of perhaps 1000-2000 needles. Each needle, with its own supply of yarn, stitches a line of loops into a backing fabric. If the loops are left intact a loop-pile carpet is produced; alternatively, by cutting the loops a cut-pile carpet is formed. To finish the carpet a secondary backing is glued to the back of the carpet to prevent it stretching and to firmly anchor the tufts.

Figure 20.37 shows the actions required to produce a cut-pile carpet.

Figure 20.37 Actions in cut-pile tufting.
Source: Wood, Canesis Network Ltd (2007).



While tufting cannot produce the complex pattern designs possible with woven carpets, patterning mechanisms that control of sideways movement of the needles and tension selected yarns to 'bury' them in the pile and become invisible makes simple yet attractive designs possible.

Wool and wool rich carpet blends invariably comprise wool components that are coarser than 30 microns, and generally between 36-40 microns. Mostly woollen-spun yarns are used, but semiworsted yarns are also quite common in products where a lean straight yarn is not a disadvantage. Worsted yarns are only used in the finest of carpet yarns used in weaving. Common blends with wool include:

- 20% nylon to provide superior abrasion resistance
- ~ 10% low melting point polyester to give enhanced appearance, and appearance retention in use
- coloured effect materials (e.g. dyed noils) to give a berber or tweed effect
- up to 50% polypropylene to produce a cheaper carpet with wool-like features

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Readings

The following readings are available on CD

1. AWTA, Testing the Wool Clip, Australian Wool Testing Authority.
2. Lamb, P.R. and Yang, S. 1998, 'The commercial impact of fibre properties on spinning,' *Proc. IWTO Technology and Standards Committee Meeting*, Dresden.
3. Canesis Network Ltd., 2003a, Wool textile manufacture.
4. Canesis Network Ltd., 2003b, Yarn properties and specification (2003).
5. Phillips, D.G., Piper, L.R., Rottenbury, R.A., Bow, M.R., Hansford, K.A. and Naylor, G.R.S. 1991, The significance of the fibre diameter distribution to the wool industry, CSIRO Textile and Fibre Technology Report No. G72.
6. Prins, M., Lamb, P.R and Finn, N. 2001, 'Solospun™ - The long staple weaveable singles yarn,' An odyssey in fibers and space, *Textile Institute 81st Conference*, Melbourne, Australia.
7. Teasdale, D.C. and Cottle, D.J., 1991, Chapter 15 - Wool preparation, marketing and processing, in: *Australian Sheep and Wool Handbook,* (ed) Cottle, D.J. WRONZ Developments, ISBN 0 909605 60 2.
8. Wood, E.J. 2000, *Tangling With Wool,* WRONZ, ISBN: 0-908974-22-1:
    - What makes a good yarn (Chp 7)
    - More good yarns (Chp 8)
    - Woven versus knitted (fabrics) (Chp 13)
    - Walk on wool (carpets) (Chp 18)
    - Wool is not thick (Chp 4)
    - Hollow wool (Chp 5)
    - Flexy fibres (Chp 9)

Activities

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@ Submit answers via WebCT

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Assignment Questions

@ Choose ONE question from ONE of the topics as your assignment. Short answer questions appear on WebCT. Submit your answer via WebCT

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Summary

Summary Slides are available on CD
This topic provides an overview of wool, its properties and textile utilisation. Despite the advent of man-made fibres during the 20th Century and the dominance they now enjoy in many areas of textiles, wool remains a much-valued fibre for quality apparel, floor coverings and other interior textiles.

The key fibre properties that are influenced by sheep genetics and management, and the conditions under which wool is grown (i.e. diameter, length, strength, crimp, colour and contamination of various types) determine both the processing route and its suitability for a wide range of end-uses. All wool must be scoured before yarn manufacture, to remove the grease, suint and other extraneous material. From this stage, the woollen, worsted and semiworsted routes for converting loose wool into yarn have different wool requirements, involve different machinery and produce yarns with distinctly different characteristics. However the principles of the major steps, i.e. carding and spinning are very similar. Irrespective of the processing route, the wool must be opened and the fibres separated and mixed, to enable a continuous, even strand to be formed. This strand simply requires twist to be added to become a yarn.

Once the yarn is made, a fabric may be formed by weaving, knitting or tufting, each requiring yarns with specific features. The nonwovens route, in which a fabric is formed without requiring a yarn as an intermediate stage, is not considered here as it is mostly used with synthetic fibres.

References

Andar Holdings Ltd., product brochure, Andar Holdings Ltd., Timaru, New Zealand.

Auer, P. 1999, Competing Fibres, Woolwise PowerPoint presentation, Cooperative Research Centre for Premium Quality Wool.

Australian Wool Testing Authority Ltd. (AWTA), 2003, Testing the Wool Clip.

Couchman, R.C., 1996, Commercial use of prediction technology, *Top-Tech '96*, pp 21.

Crawshaw, G.H. 2002, *Carpet Manufacture*, WRONZ Developments, ISBN 0-908974-25-6.

Halliday, L.A. 2002, Woolscouring, carbonising and effluent treatments, in: *Wool: Science and Technology*, Simpson, G.H. and Crawshaw, G. (eds.) Woodhead Publishing Ltd, ISBN 1-85573-574-1.

Harrowfield, B.V. 1987, Early-stage wool processing: from scoured wool to top, *Wool Science Review*, vol. 64, pp. 44.

Hunter, L. 2002, Mechanical processing for yarn production, in: *Wool: Science and Technology*, Simpson, G.H. and Crawshaw, G. (eds.), Woodhead Publishing Ltd, ISBN 1-85573-574-1.

Lamb, P.R. 1997, Wool quality for spinners, CSIRO Textile and Fibre Technology.

Lamb, P.R. and Yang, S. 1997, An introduction to Sirolan-Yarnspec for the prediction of worsted yarn properties and spinning performance, *Proc. IWTO Technology and Standards Committee Meeting*, Boston.

Naylor, G.R.S. and Phillips, D.G. 1996, Skin comfort of wool fabrics, *Top-Tech 1996,* pp. 356.

Prins, M., Lamb, P., and Finn, N. 2001, Solospun™ - The long staple weavable singles yarn, *Textile Institute 81st World Conference,* Melbourne, April 2001.

Oxtoby, E. 1987, *Spun Yarn Technology,* Butterworths, ISBN 0-408-01464-4.

Parton, K. 2002, Practical wool dyeing, in: *Wool: Science and Technology*, Simpson, G.H. and Crawshaw, G. (eds.), Woodhead Publishing Ltd, ISBN 1-85573-574-1.

Roberts, S. 1996, Blend partners for natural fibres, Wool Record, May 2096, p 57.

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Russell, K., McDowell, D. Ryder, I. and Smith, C. 2002, Manufacture of wool products, in: *Wool: Science and Technology*, Simpson, G.H. and Crawshaw, G. (eds.), Woodhead Publishing Ltd, ISBN 1-85573-574-1.

Teasdale, D.C., 1995a, The Wool Handbook – The A to Z of Fibre to Top, ISBN: 0 646 24034 X, pp 56

Teasdale, D.C. 1995b, The Wool Handbook – The A to Z of Fibre to Top, ISBN: 0 646 24034 X, pp 49.

Teasdale, D.C. 1995c, The Wool Handbook – The A to Z of Fibre to Top, ISBN: 0 646 24034 X, pp 53.

Teasdale, D.C. 1995d, The Wool Handbook – The A to Z of Fibre to Top, ISBN: 0 646 24034 X, pp 55.

Teasdale, D.C. 1995e, The Wool Handbook – The A to Z of Fibre to Top, ISBN: 0 646 24034 X, pp 78.

Teasdale, D.C. 1995f, The Wool Handbook – The A to Z of Fibre to Top, ISBN: 0 646 24034 X, pp 51.

Teasdale, D.C. and Cottle, D.J., 1991, Wool preparation, marketing and processing, in: *Australian Sheep and Wool Handbook,* Cottle, D.J. (ed.), WRONZ Developments, ISBN 0 909605 60 2.

Wood, E.J., 2000, Flexy fibres, from Tangling With Wool, WRONZ, ISBN 0-908974-22-1.

Wooltrak, 2002, Australian Wool Statistics Yearbook – 2001-2002 Season, p 61.

WoolPro, 2002, Statistical Handbook: 2001-2002, WoolPro.

Glossary of terms

Apron	A small belt that assists in controlling fibres in the drafting zone of a worsted and semiworsted spinning frame
Backwashing	The washing of wool sliver before or after gilling and/or combing
Barbe	Measures the mean length (in mm) of fibres in a sliver or top, based on a weight-biased distribution. The key length results from the Length After Carding Test
Bilateral differentiation	The clustering of the two main types of cell (orthocortex and paracortex) in the two halves of the cross-section of a wool fibre
Brightness	The brightness (as opposed to dullness and greyness) of wool; expressed as Y - the green component of the tristimulus values produced by a colorimeter
Bobbin	A slightly tapered tube, mounted on the spindle, onto which the yarn is wound in ring spinning
Burr beater	A brushed roller on a worsted and semiworsted card that works in tandem with a Morel roller to eject vegetable matter from the wool flow
Bulk	The volume occupied by a standard mass of prepared wool sample under a standard pressure, measured in cm3/g. Normal range: 18 – 36 cm3/g
Carbonising	A chemical (acid) process for eliminating vegetable matter from wool by degrading it to a friable state
Card	Machine for carrying out carding, the disentangling, cleaning and mixing of fibres to produce a continuous web or sliver suitable for subsequent processing
Carding	The action of toothed rollers in a carding machine to open and blend clumps of scoured wool for spinning, and remove vegetable matter

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Carding wool	Wool more suited for woollen processing (as opposed to combing wools)
Carder	The second half of a woollen card, between the intermediate feed and the condenser section
Clearing	Automatic and detection and removal of yarn faults
Clothing	The pinned, spiked or toothed metallic layer covering the surface of a card roller
Comb	Machine for carrying out combing (removal of short fibres, vegetable matter and neps) and straightening of fibres in the worsted processing route
Combing wool	Superior wool with suitable properties for worsted processing (as opposed to carding wools)
Condenser	The final section of a woollen card; divides a broad web of fibres into narrow strips which are then consolidated by a rubbing action into slubbings.
Count	See Linear density
Coefficient of variation of fibre diameter	A measure of the range of a fibre diameter distribution, the standard deviation as a percentage of the mean fibre diameter
Comfort factor	The percentage of fibres in a fibre diameter distribution which are finer than 30 microns
Cotting	The felting and matting of wool on a sheep's back, usually associated with fleece tenderness
Crimp frequency	The number of crimp waves per centimetre of staple length
Crossbred	In New Zealand, the group of dual purpose breeds that produce coarser wool (> 30 microns) and meat (e.g. Romney, Coopworth, Perendale, Borderdale,..)
Denier	A measure of the mass per unit length, used for manmade fibres and filaments, related to fibre thickness
Doffer	The large, slow roller that removes fibres from the swift of a card
Drafting	Process of reducing the linear density of a sliver or roving by causing the fibres to slip relative to each other. Occurs in the drafting zone. (See Roller Drafting)
Droppings	Fibres and wool contaminants that fall beneath a carding machine
Dry spinning	Woollen yarn making using a sufficiently low level of lubricant that no subsequent scouring step is required
Elastomeric fibre	A polymer fibre capable of extreme extension (up to around 100%) and complete recovery; examples - Lycra, Spandex
Elongation	The length by which a yarn can stretch (expressed as a percentage of the original length) before it breaks
Evenness	(or regularity, uniformity) In slivers, the absence of thick and thin places; in yarns the absence of thick and thin places, periodic variations in thickness or neps or slubs

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Fancy	The fast, long-bristled roller on a card that raises fibres to the surface of the swift so that they are more easily removed by the doffer
Feed sheet	The slow-moving conveyor that transfers the wool from the feed hopper to the first stage of the card
Finishing	Processes carried out on a fabric to improve its handle, appearance or stability
Fly	Fibres floating away from the wool flow and settling on flat surfaces etc
Folded yarn	A yarn composed of two or more singles yarn, twisted together (sometimes called twisted yarn or plied yarn)
Evenness	The absence of variations in thickness or occurrences of thick and/or thin places in a sliver or yarn; the terms *uniformity* and *regularity* are also used
Fibre curvature	The inverse of the radius of arc of a segment of a fibre snippet, expressed in degrees per mm
Fibre diameter distribution	A frequency table or histogram depicting the diameter range of fibres in a wool sample, often showing the proportion of fibres in 1 mm intervals
Gilling	A process to align the fibres in a sliver by drawing through an array of pins
Gillbox	A machine for carrying out the gilling operation
Gilling	The process of aligning fibres in a sliver by drawing lines of pins through it (as well as performing drafting by drafting rollers)
Hank dyeing	Process where hanks of finished yarn are immersed in dye liquor for dyeing
Heald	A wire with an eye in the centre through which a warp yarn is threaded so that its vertical movement can be controlled in weaving
Hauteur	Measures the mean fibre length (in mm) of fibres in a sliver or top, based on a cross-section-biased distribution. Predicted for fine wools from TEAM formula
Intermediate feed	Mechanism in a woollen card for transferring the web from the scribbler section to the carder section, and cross-lapping the web to improve side-to-side blending
Kemp	A brittle, highly medullated fibre found in the fleece of some sheep, a remnant of the outer coat of primitive sheep breeds
Keratin	The protein substance forming the wool fibre, actually comprises three types: low sulphur, high sulphur, high-glycine tyrosine proteins
Kilotex	The unit of linear density for slivers and tops - 1 ktex = 1 gram per metre
Knitting	The formation of a fabric by the intermeshing of loops of yarn
Laserscan	A sophisticated instrument for measuring the fibre diameter distribution of snippets by detecting their shadow as they are transported through a laser beam
Length After Carding Test	A test for determining the fibre length characteristics, especially barbe, on a carded sample of scoured wool
Linear density	The mass of material in a given length, i.e. grams per kilometre (the tex) and grams per metre (kilotex); used for slivers and yarns (often called yarn 'count')

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Loose stock dyeing	Dyeing process where the material is in loose form, e.g. scoured wool, carried out before carding
Lubricant	An emulsion of a special oil and water, sprayed as a mist onto wool before carding to aid processing (sometimes called a fibre processing aid)
Lustre	The glossy appearance of fibres due to a high level of light reflection
Mean fibre diameter	The average thickness of a sample of wool fibres (in microns), derived from the fibre diameter distribution
Medulla	Hollow continuous or discontinuous network of collapsed cells extending along the core of some wool fibres
Medullation	The property arising from a collection of fibres containing medullae
Micron	Unit of fibre diameter, 1 micron (μm) is one millionth of a metre, alternatively the term *micrometre* may be used
Morel roller	A roller on a worsted card with special flat-topped teeth which is designed to release vegetable matter fragments by the action of a burr beater
Nep	Small entangled knot of fibres; often produced in carding
Noils	Fibrous waste removed by a comb; may be suitable for recycling
Newton per kilotex	The unit used for measuring the tensile strength of wool staples; wools exceeding 30 N/ktex are considered sound
Oddments	Inferior types of greasy wool other than the fleece wool – includes pieces, bellies, necks, locks, crutchings, stains, dead wool, etc.
OFDA	An instrument for measuring the fibre diameter distribution using an automated microscope, video camera and image analysis techniques
Optical Fibre Diameter Analyser	See OFDA
OPTIM	A process developed by CSIRO involving the controlled stretching wool fibres to make them finer and to impart a silk-like, lustrous appearance
Polyamide	A synthetic polymer fibre, commonly referred to as *nylon*
Position of break	The location of the weakest part of a wool staple, usually placed in one of three zones - tip, middle and butt (or base)
Prickle	The uncomfortable sensation involving the stimulation of nerve endings in the skin by short fibres protruding from the surface of a fabric
Peralta roller	A pair of heavy steel rollers that apply high pressure to the card web, crushing particles of vegetable matter so they fall away more readily
Reed	A vertical array of wires in a loom that (1) separate the warp threads, (2) guide the shuttle or rapier, and (3) beat up the weft threads
Regain	Moisture content of wool or yarn; calculated by expressing the mass of water in a sample as a percentage of the original mass of the sample (i.e. before it is dried)
Ring spinning	A spinning system in which twist is inserted in a yarn using a traveller revolving around a ring

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Roller drafting	The process of drawing out a sliver or roving to reduce its linear density using two pairs of rollers having different surface speeds. The region between the pairs of rollers is the drafting zone
Roving	A fine, even, well-aligned strand of fibres formed by drafting a top; the input material to worsted spinning
Regenerated fibre	A man-made fibre produced from a naturally occurring polymer, for example wool cellulose is converted into rayon
Resilience	The extent to which a material (e.g. carpet pile) recovers its original shape after a deforming force is removed
Resistance to compression	The pressure required to compress a standard mass of wool into a fixed (small) volume. Typical values range from 5 – 15 kPa
Semiworsted processing	The route by which fibre is converted into yarn by a route that involves carding, gilling and spinning to give a yarn intermediate in properties between woollen and worsted
Sirolan Laserscan	See Laserscan
Sliver	A continuous untwisted strand of fibres produced by carding and by gilling; it may, or may not, have some vegetable matter and have well-aligned fibres
Scribbler	The first half of a woollen card, between the feed hopper and intermediate feed
Semiworsted route	The process of spinning yarn from a sliver produced by carding and gilling, the sliver not having been combed
Setting	The process of stabilising the twist in a yarn by heat, steam or chemical means
Shed	The opening formed when the warp yarns are separated in the weaving operation
Singles yarn	The twisted strand produced by ring spinning (as opposed to a folded yarn)
Sliver	An untwisted rope of fibres, produced by carding or gilling
Slub	A short, abnormally thick place in a yarn
Slubbing	A thin untwisted strand of fibres produced by the tape condenser of a woollen card
Solospun	An attachment to each spindle of a worsted ring spinning frame that produces a singles yarn of superior abrasion resistance for weaving
Spindle	The driven shaft on a ring spinning frame that rotates the bobbin
Stripper	A small, high speed roller on a card that transfers fibres from a worker roller back onto the swift
Swift	The large roller with a high surface speed that moves fibres through a card
Spinning	(a) The entire process of converting fibre into yarn, or (b) the specific step where the yarn is formed by twisting a strand of fibres as they are wound onto a package
Staple	A well-defined bundle of wool fibres removed intact from a fleece

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Synthetic fibre	A man-made fibre produced from a polymer assembled from chemical compounds, e.g. by-products of petrochemical industry
Tape condenser	The final unit of a woollen card that (1) divides the web into narrow strips, and (b) uses a rubbing action to convert each strip of fibres in slubbing
Tape scour	A series of bowls (scouring and rinsing) interspersed with squeeze rollers, used for scouring (and sometimes chemical setting) of yarns. The hanks of yarn are transported by tapes that run through each bowl
Tenacity	The force required to break a yarn or sliver, as a ratio of its linear density. Unit: Newtons per tex (N/tex)
Tex	The unit of linear density for yarns (1 tex = 1 gram per km)
Top	A combed sliver of exceptional cleanliness, evenness and fibre alignment; the input material for worsted spinning
Topmaking	The production of a top using the sequence of operations: carding, gilling and combing
Traveller	The small metal or plastic guide through which the yarn passes to the spinning (or twisting) package. It is mounted on the ring and is dragged around by the yarn
Tufting	Formation of a pile fabric where loops of yarn are inserted in a base fabric
Twisting	The combining two or more singles yarns to produce a two-fold yarn (or three-fold, etc.)
Tender	Implies that fibres have a weakness at some point in the staple; the opposite of sound
Tensile strength	The force required to break a staple, sliver, top or yarn; usually measured in Newtons per kilotex
Thermoplastic	A fibre is deformable by heat and pressure without any accompanying chemical change. The process is reversible
Topmaking	The processes of carding, gilling and combing to form a top
Tristimulus values	The amounts of the three primary colours (red, green and blue) required to be combined to match the colour of an object. The results produced by a colorimeter
Vegetable matter	Cellulosic wool contamination consisting of burrs, seeds, thistle heads, hard heads, straw, chaff and small pieces of twig and bark
Virgin wool	New and unused wool that has not been reclaimed from a spun, woven, knitted or felted article
Warp	The set of threads fed lengthwise into a weaving loom, often from a warp beam
Web	The thin, uniform sheet of fibres produced by a card
Weft	The threads inserted width-wise in a loom when forming a woven fabric
Woollen route	The production of yarn by carding on a woollen (condenser) card, followed by ring spinning and twisting

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Wool scouring	High production, gentle washing of wool to remove wool grease and other contaminants before yarn manufacture
Worker	A slowly rotating roller on a card that interacts with the swift to open and blend the tufts of fibre
Worsted route	The production of yarn from combed wool, in which the fibres are reasonably parallel. It uses the processes of carding, gilling, combing, backwashing, roving, ring spinning and twisting
Woollen processing	The conversion of wool into a relatively disorganised yarn by condenser carding and spinning
Worsted processing	The conversion of wool into a smooth, even, fine yarn by a series of steps involving carding, gilling, combing and spinning

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