9. Principles of Wool Carding

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Learning objectives

On completion of this topic you should be able to:

- Name the key rollers in a card and explain their functions
- Describe the various card roller interactions and their purposes
- Explain how fibres gain a hooked configuration in card sliver, and how these hooks are subsequently removed
- Describe the process of fibre breakage on a card and the factors that influence the level of breakage
- Sketch how the fibre length distribution changes in carding
- Explain the terms *collecting fraction* and *delay factor*, and their relevance to the mixing ability of a card
- Describe, with the use of a suitable diagram, the effect on carding production of a rapid change in feed rate.
- Describe a *nep*, and outline the factors that contribute to nep formation

Key terms and concepts

Carding section, carding rollers, carding actions (working, stripping, raising), hook formation, fibre breakage, withdrawal forces, fibre length distribution, fibre mixing, worker collecting fraction, delay factor, neps.

Introduction to the topic

Irrespective of which of the three routes (woollen, worsted or semiworsted) is used to process wool into yarn, the card (or carding machine) plays an essential part. It separates the entangled clumps of fibres into a web of individual fibres by working them between a series of closely spaced moving surfaces which are covered with pointed wire, pins or teeth (the card *clothing*). Important considerations in carding are the processes of fibre individualisation, formation of the web, the extent and configuration of the fibres in the web, and the degree of fibre damage occurring during carding. These are important because, in processing stages after to carding, excessive fibre breakage and poor fibre configuration (i.e. straightness) may lead to unacceptable yarn irregularity and imperfections.

Carding technology is not new – the first carding device was patented over 250 years ago, and the principles and practices of carding have changed relatively little in the past hundred years. And, in comparison with other textile machines, the operating principles of a carding machine have been quite poorly understood. As a result, carding has been more of an art than a science, although the modern automatically controlled machines rely less on the skill and experience of the operator than before to achieve good results.
Worsted and semiworsted cards are very similar with respect to their design and operation. The differences mostly relate to layout (i.e. the number of rollers of each type). On the other hand, a woollen card is different to these types of cards in a number of significant ways. These machines and practical aspects of carding are covered in the Topic 18 – *Wool Carding Technology*.

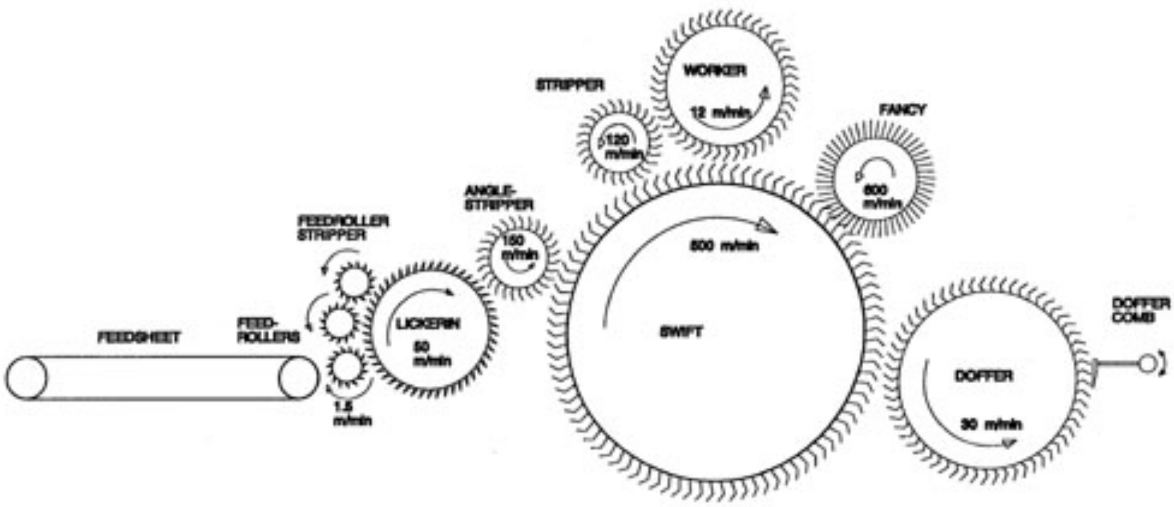
The book by Lawrence (2002) is provides excellent coverage of carding principles. It deals with the theoretical aspects in more detail than is possible in this topic. Other useful sources of relevant information are Oxtoby (1987), Lord (2003) and WIRA (1968).

9.1 The functions of carding

The card has three main functions:

1. to open and disentangle the blend to a single fibre state and mix it homogeneously with minimal breakage of fibres or formation of neps
2. to remove impurities such as vegetable matter
3. to deliver the carded material in an appropriate form to the next stage of processing (i.e. as a web, sliver or slubbing).

Figure 9.1 Basic components of a card, showing the roller speeds and directions. Source: Wood, 2006.



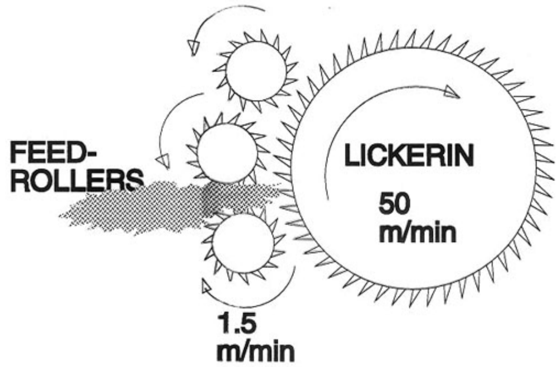
The basic components of a card are shown in Figure 9.1. This diagram is a simplification and more closely represents one section of a multi-section card. A full-size commercial carding machine usually comprises two or more of these units placed end to end. A card consists of cylinders (of large diameter) and rollers (of smaller diameter), each with a unique name (*lickerin, swift, worker, stripper, fancy, doffer* etc.). While only one worker/stripper pair is shown here, it is common to have 4 – 6 pairs of worker and strippers positioned around the circumference of a swift.

Some card rollers rotate at high speeds (with surface speeds of several hundred metres per minute or more), while others rotate relatively slowly, as shown in Figure 9.1. For example the surface speed of a worker roller is around 10-12 metres per minute. In most cases the gaps between the swift and the other rollers are only about 0.5 – 1 mm, and magnets are often placed before the feed rollers to ensure that no metallic objects enter the card and damage it.

Feed-roller and lickerin actions

The feed sheet is a short, wide conveyor that slowly delivers the fibre to the feed rollers. The licker-in snatches the clumps of fibre from the feed rollers. The teeth (or pins) of the licker-in carry out the initial opening of the clumps into smaller tufts by tearing at the clumps restrained by the slowly rotating feed rollers, and some fibres are broken at this stage (Figure 9.2). The tufts are transferred from the licker-in to the main cylinder (or swift) by the transfer roller. The tufts, which are partially separated by the time they reach the swift, are separated further when they encounter the worker roller.

Figure 9.2 Action of feed rollers and lickerin. Source: Wood, 2006.



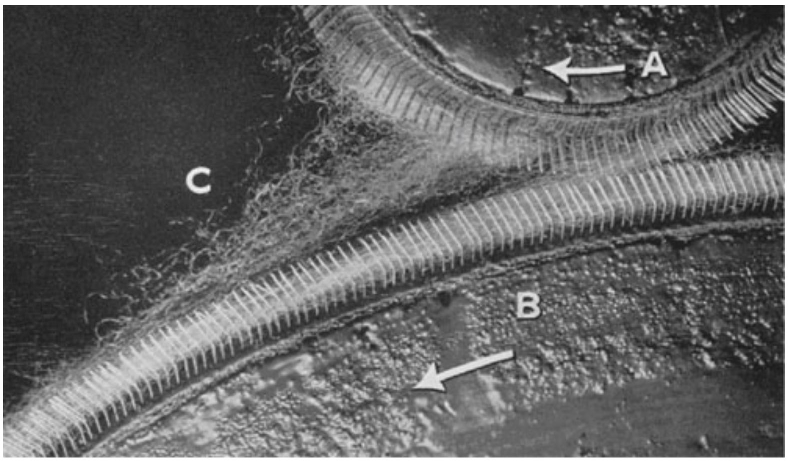
Worker-swift action

The separation of tufts into individual fibres is the primary function of carding. To a first approximation, each tuft is "halved" at a working point, i.e. where the worker and swift compete for a tuft (Figure 9.3). The action is called 'point-to-point' because of the directions from which the teeth of the two rollers approach each other.

An individual tuft may contain roughly 10,000 fibres and needs to be "halved" n times to reach full individualisation of the fibres, where $2^n = 10000$. Since $2^{13} \sim 10000$, this simple analysis suggests that around 13-14 working points are required on the entire card. In practice, most tufts undergo more than one revolution on the swift and are therefore recycled through a working point a number of times.

The working action involves a contest between the worker (A) and the swift (B) for a tuft of wool (C). Fibres caught by the worker teeth are slowly moved away from the swift and around to the accompanying stripper roller. The stripper re-deposits the fibres back onto the swift.

Figure 9.3 Point-to-point action (swift and worker). Source: Wood, 2006.



Other carding actions

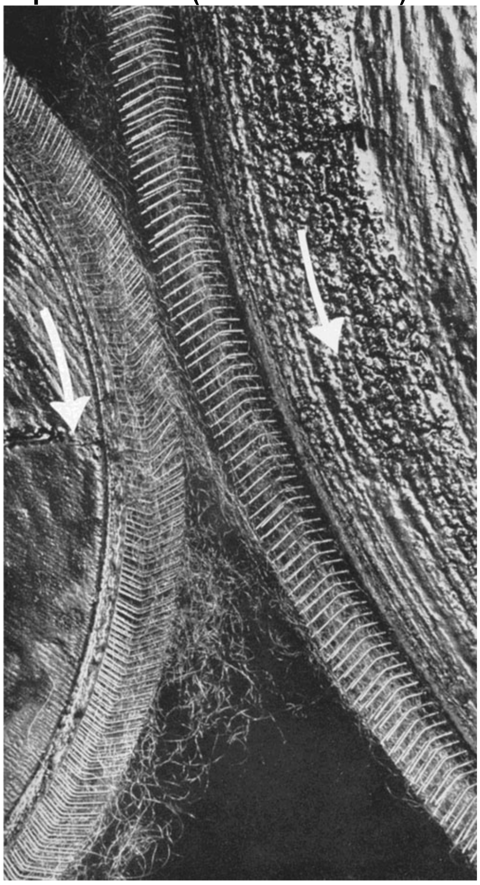
Fibres, or small tufts of fibre, are similarly separated by the doffer, which removes a proportion of fibres from the swift in the doffing zone. The fibres retained by the doffer are removed by the doffer comb in the form of a sheet of partially aligned fibres, the web, (and hence are not returned to the swift). Fibres not taken by the doffer stay on the swift to be re-worked and mixed with fresh fibre. The variability in the time that a fibre spends on the card (i.e. the number of workings and swift revolutions it undergoes) is primarily responsible for the mixing action of the card.

Between the worker and the doffer is the fancy, which has much longer and more flexible pins than any other roller. The purpose of these long pins is to lift the fibres to the surface of the teeth of the swift so that they can be captured more easily by the doffer.

The various actions of the card rollers fall into three groups:

- Point to point, which results in some fibres being retained by each surface (working and doffing), (Figure 9.4 shows the doffer (left) removing fibres from the swift (right))

Figure 9.4 Point-to-point action (doffer and swift). Source: Wood, 2006.



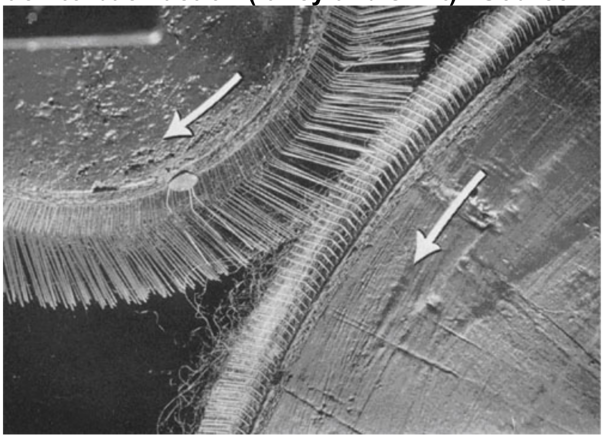
- Point-to-back, where all the fibres are transferred from one surface to another (stripping). Because the fibres merely slip off the teeth of the worker onto the stripper, negligible fibre breakage occurs. The transfer of fibres from the stripper back onto the swift is also a point-to-back action.

Figure 9.5 shows the stripper (right) removing fibres from the worker (left).

Figure 9.5 Point-to-back action (worker and stripper). Source: Wood, 2006.

- Back-to-back, which is an action only carried out by the fancy in conjunction with the swift. This action raises embedded fibres above the surface of the swift teeth, thus facilitating their removal by the doffer (In Figure 9.6 the fancy is on the left and the swift is on the right). This is the only roller interaction on a card where the teeth of two rollers are in contact with each other.

Figure 9.6 Back-to-back action (fancy and swift). Source: Wood, 2006.



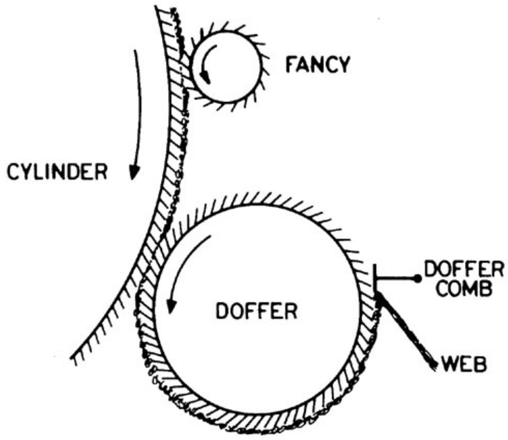
Auer (1999) describes, by means of simple diagrams, the interaction of the fibre with card teeth in the working and stripping actions.

Removal of fibres from the card

The removal of fibres from the card depends on probabilities, i.e. the probability that a fibre will be removed by the doffer as it passes by on the swift. Consequently, the passage of a fibre through a section of a card can vary from a single passage from feed roller to doffer without passing around any workers, to a complex path leading around each worker a large number of times, and repeated passages around the swift before doffing finally occurs.

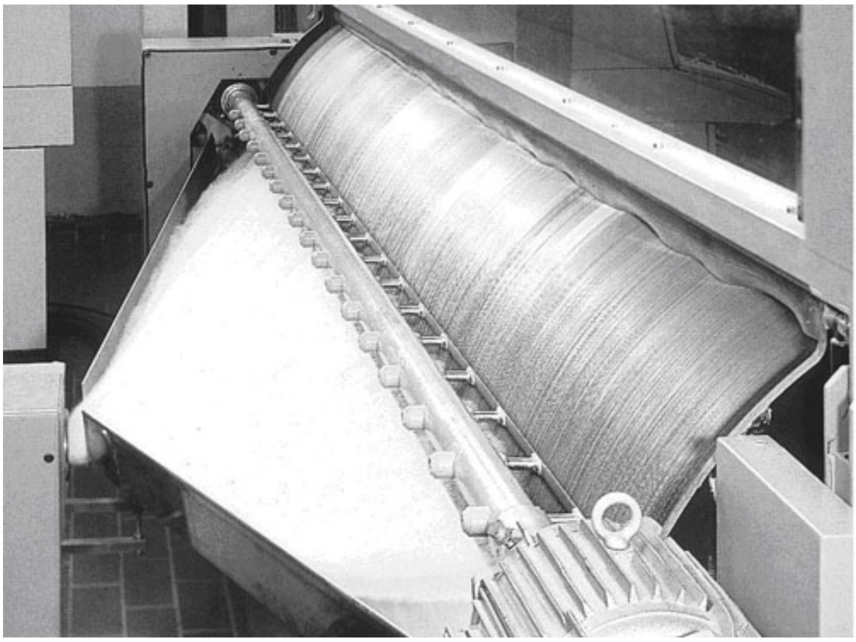
The removal of fibres from the final section of a worsted or semi-worsted card is accomplished by a doffer and doffer comb, and often in conjunction with a fancy roller (as shown in Figure 9.7). However, in modern cards fitted with metallic wire, the fancy is often omitted.

Figure 9.7 Removal of fibres from the cylinder (swift). Source: Wood, 2006.



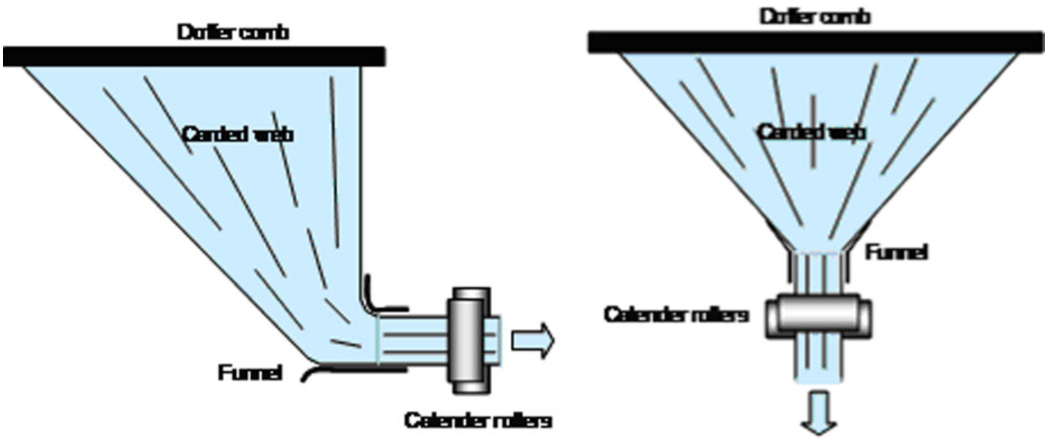
Fibres transferred to the doffer are stripped in web form by the oscillating comb, condensed into a sliver (Figure 9.8) and coiled into a can. The doffer comb is set close to the doffer roller clothing and reciprocates with a stroke of up to 40 mm. At each downward stroke it pushes fibres down the back of the doffer teeth, and the web is drawn away.

Figure 9.8 Removal of the web by the doffer comb. Source: Thibeau (NCS Schlumberger).



The doffer roller should not move more than about 12 mm for every stroke of the comb. In addition, the doffer comb frequency is limited to about 3000 strokes per minutes and this sets a limit to the maximum surface speed of the doffer. This speed limitation has led to the replacement of the doffer comb by draw-off rollers where high speed carding can be applied.
As an alternative to the doffer comb, a draw-off roller is now used on some cards, especially where high speed carding is involved. The fibres, which are near the tips of the doffer teeth, are removed by a wire clothed roller that intersects the doffer clothing by about 2 mm. The fibres are removed from the backs of the doffer teeth with a back-to-back action.

Figure 9.9 Methods of web removal from the card. Source: Wood, 2006.



The full-length web from the doffer taken into a ‘centre draw’ or ‘side draw’ arrangement and is condensed into a sliver by being passed through a funnel and a pair of pressure rollers (Figure 9.9). These rollers, called *calender* rollers, run at slightly higher surface speed than the doffer. In this zone the fibres are under minimal control and are subject to differential drafts (slippage to produce stretching) ranging from a minimum along the axis of the carding machine to a maximum at the more inclined web edge. Under these conditions fibres are likely to change their configurations, which involve both hook formation and removal. The effect will be less with the centre draw arrangement than the side draw arrangement.

The mechanism by which fibres are captured by the teeth of the doffer inevitably causes fibres in the card sliver to become hooked. The hooks formed on the doffer are predominantly ‘trailing’ hooks, i.e. the fibre end is ahead of the looped part.

The hook in a fibre enables it to be retained on a doffer wire, and not slip off it as a result of the tugging force of the swift wires on its free end (Figure 9.10). However, a smaller proportion of fibres will have leading hooks, double hooks or may have no hooks (i.e. straight). It has been estimated that 50% of fibres have trailing hooks, 15% have leading hooks, 15% have hooks at both ends and only 20% emerge from carding completely straight.

Fibre straightening in the second and subsequent gilling steps removes these hooks. In successive gilling steps the sliver is reversed so that trailing hooks become leading hooks, and vice versa (Figure 9.11).

For example, at the second gilling, a fibre with a trailing hook is withdrawn from the array of pins by the front roller and the resulting combing action tends to eliminate the hook (Figure 9.12). The surface speed of the front rollers is higher than the speed of the pinned fallers.

Figure 9.10 Formation of trailing fibre hook on doffer tooth. Source: Wood, 2006.

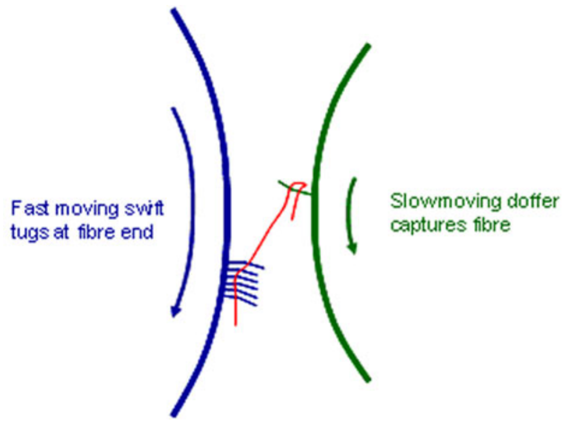


Figure 9.11 Trailing hooks become leading hooks when sliver direction is reversed. Source: Wood, 2006.

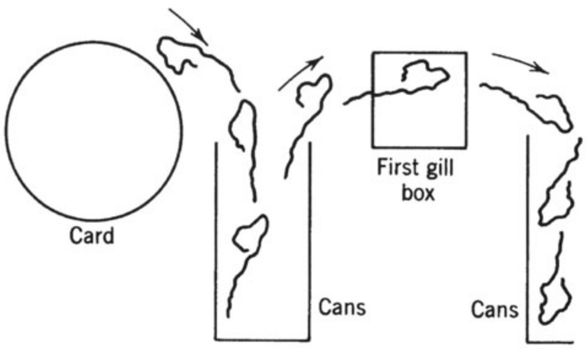
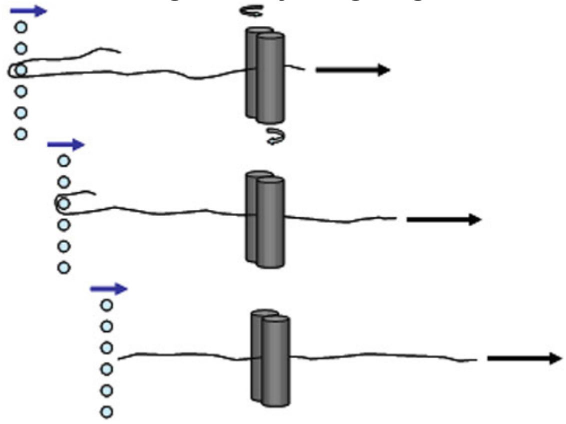


Figure 9.12 Removal of a trailing hook by the gilling action. Source: Wood, 2006.



Fibre hooks are also formed in the interaction between swift, worker and stripper (Auer 1999).

9.2 Fibre breakage in carding

There is a strong price incentive (around 10c per mm) for achieving a mean fibre length of a top close to 65 mm (above this length the price tends to level off) (Robinson 1998). Robinson (1998) has estimated that a reduction in the value of a 21 μm top of around 20 cents per kg can arise from a reduction of 2 mm in the mean fibre (Hauteur).

Maximising fibre length in the top can be achieved by:

a) using longer raw wool (an expensive strategy), or
b) reducing the amount of fibre breakage in early stage processing, especially carding.

The primary function of carding is to perform the opening and mixing functions with the minimum level of fibre breakage. Fibre breakage may happen where the opening and subdividing of the tufts of fibre occurs (Robinson 1996; Hansford 1996).

The opening of tufts of fibre is carried out at all locations on the card where a 'carding action' takes place. This includes the zones between the feed rollers and the licker-in, between the swift and the workers, and between the doffer and swift. Opening of the tufts to the extent of complete separation of the fibres is virtually completed by the time the material has reached the last swift of the card.

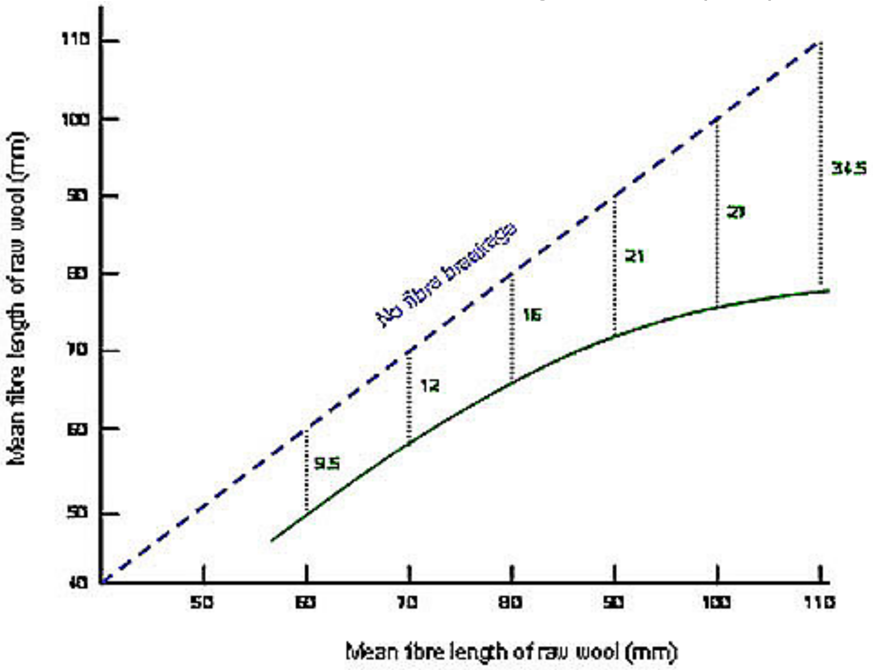
The amount of fibre breakage that occurs in carding acts against the objective of preserving of the fibre length of the blend, and is an important commercial consideration. Some fibre breakage is inevitable, but if it is excessive, the carding yield will drop. This is because the card waste will increase in amount due to a higher level of short fibres which cannot be retained in the web or on the clothing. Shortened fibres also lead to inferior spinning performance and weak yarns.

Fibre length and strength effects

The likelihood that a fibre will break in carding depends on its length – the longer the fibre the greater the chance that it will break. The underlying reason is the force required to withdraw a fibre from a tangled mass; this is the force required to overcome the friction between the fibre and those with which it is in contact. A longer fibre has more contact points with other fibres and thus a higher force is required to overcome friction. If the force required for complete withdrawal of a fibre exceeds the breaking strength, the fibre will break.

As a result, carding is a fairly severe action, with typically 20-40% of fibres being broken. It has been estimated that 90% of the fibre breakage that occurs in converting scoured wool into top occurs in carding. The effect of fibre length is exemplified by the results of Aldrich and co-workers (Aldrich, Kruger & Turpie 1970). The mean fibre lengths before carding and after carding and gilling were determined on a range of merino wools and the results are shown in Figure 9.13. Had no fibre breakage occurred, the mean fibre lengths would have as shown by the straight dashed line. The decrease in mean fibre length due to breakage at different lengths of raw wool is indicated by the vertical dotted lines, with the actual reductions shown (in mm). It is clear that the reduction in mean fibre length increases slowly from short to medium length wools, and then much more rapidly from medium to long wools.

Figure 9.13 Mean fibre length after carding and 3 gillings versus mean fibre length of raw wool. Adapted from: Aldrich, Kruger & Turpie (1970).

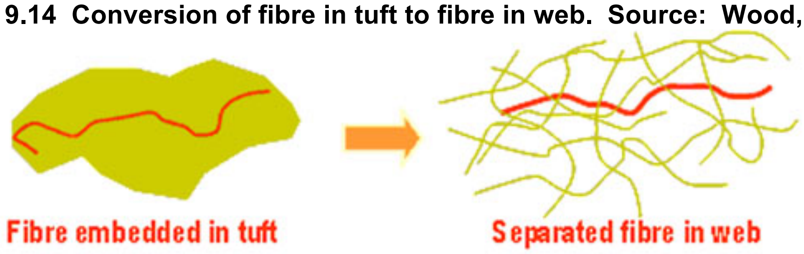


Fibre strength is important too. Wool fibres will tend to break more readily than, say, nylon staple fibre of similar diameter. If the wool fibres are damaged in loose stock dyeing (a colouration step not usually carried out in worsted processing), or they contain weak points, as in the case of tender wool, the likelihood of them breaking on the card is increased.

Mechanism of fibre breakage

In essence, the task of carding is to take a fibre that forms part of a tuft and convert into a part of a web (Figure 9.14).

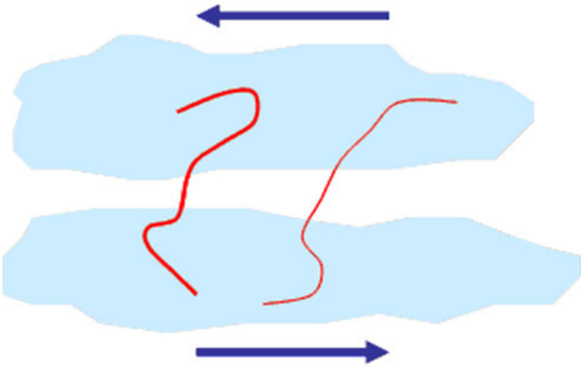
Figure 9.14 Conversion of fibre in tuft to fibre in web. Source: Wood, 2006.



The fibre breakage, which is inevitably associated with this process, can occur in several ways:

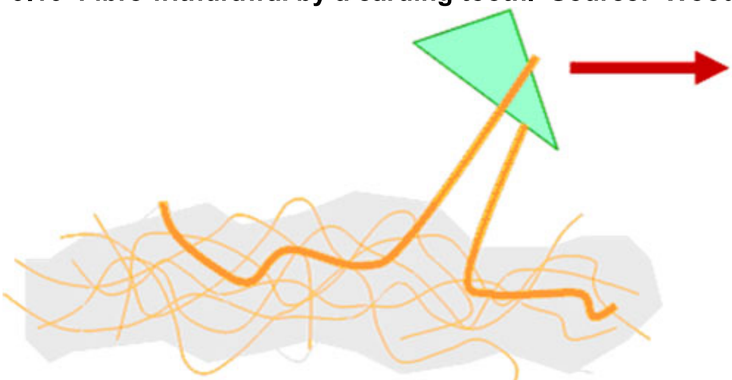
(a) When a clump or tuft is separated into two parts at a working point, some fibres will be embedded in both parts (Figure 9.15). If this separation is to occur without these 'connecting' fibres being broken, their ends must be able to readily slip out of one part of the tuft or the other. Slippage will not be possible if the withdrawal force of a fibre is higher than its breaking force. The withdrawal force will tend to be high if the fibre is long – these fibres inevitably have a high probability of breaking in carding than short fibres.

Figure 9.15 Tuft separation and fibre withdrawal. Source: Wood, 2006.



(b) A card tooth may catch a loop of fibre protruding from a tuft (which is restrained on another roller) (Figure 9.16). The fibre can only be released without breaking if either end of the fibre that is embedded in the tuft can slip free. If the fibre withdrawal force is high the fibre will be broken. A sharp card tooth may actually cut the fibre loop.

Figure 9.16 Fibre withdrawal by a carding tooth. Source: Wood, 2006.



The force required to withdraw a fibre from a tuft is also increased if there is pressure applied to the tuft to increase the friction between fibres, and more fibre breakage is likely. This increase in pressure may occur (a) if the feed rate is too high so that a thick mass of fibre is required to move through narrow spaces between rollers, or (b) where rollers are too closely spaced, especially the feed rollers or between workers and the swift. For this reason the card settings are usually wide at the start and become progressively closer through the machine.

Excessive fibre breakage can be caused at the breast end by setting the rollers too close, by incorrect roller relative speeds, or by using the wrong type of card clothing. On the other hand, if the rollers are set too wide the web of fibres may tend to roll, leading to nep formation.

The practical consequences of fibre breakage in carding, particularly as they relate to worsted processing, are reviewed by Robinson (1998). He summarises the factors contributing to fibre breakage as follows:

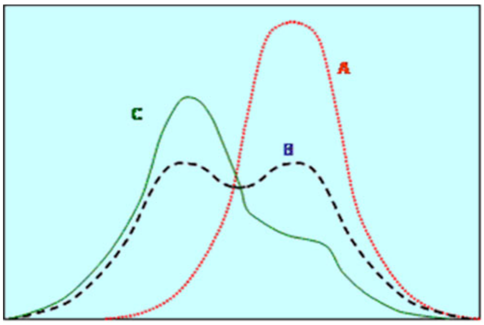
- Density of fibres being processed – i.e. more breakage will occur when a thick mat of wool is fed to a card rather than a thinner mat
- Frictional interactions between fibre in relative motion – i.e. applying a lubricant reduces frictions and reduces fibre breakage
- Frictional interactions between fibre and metal pins – also reduced by the lubricant
- Physical properties of the fibres – strength, extension, length, moisture content
- Level of entanglement and presence of impurities (e.g. vegetable matter)
- State of card clothing - clothing in poor condition leads to inefficient opening and fibre control
- Card settings – need to achieve optimum roller spacing to minimise fibre breakage (if too close) or nep formation (if too open).

Increasing the overall speed of a carding section does not significantly change the level of fibre breakage, hence the success of high speed carding (see Topic 18 – *Wool Carding Technologies*).

Changes in the fibre length distribution caused by carding

The numerical fibre length distribution shows the proportion of fibres in each length interval, according to their number. In Figure 9.17, the original fibre length (Hauteur) distribution is shown by the approximately bell-shaped curve A. The effect of significant fibre breakage is to deform this distribution so that the proportions of fibres in the shorter length intervals are increased at the expense of the fibres in longer length intervals. Curve B represents the fibre length distribution if one third of the fibres break in the middle, while curve C shows the result if two thirds of fibres are broken.

Figure 9.17 Simulated fibre length distributions. Source: Wood, 2006.



The point to note here is that a change in the breakage pattern (number of fibres breaking and position of break) alters the relative shape of the distribution. A bimodal distribution, as exhibited by curve B is a characteristic of a top made from mid-break wools.

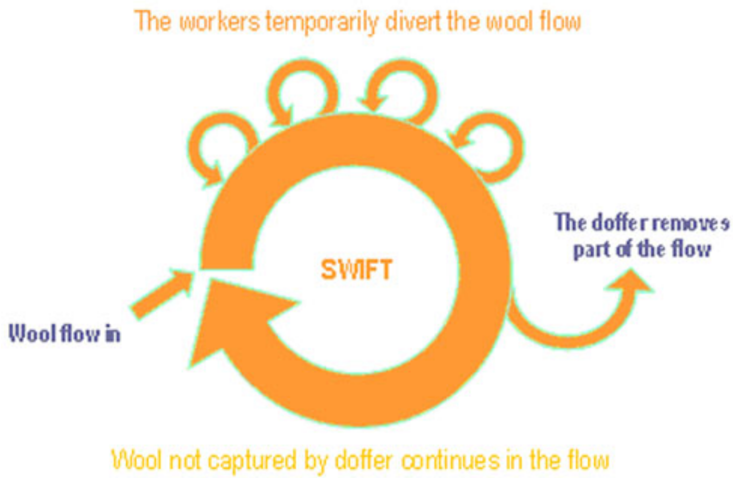
The mathematical description of fibre breakage in carding is very complex, but the interested student is referred to the paper by Carnaby and Burling-Claridge (1996) and the references contained therein.

9.3 Fibre transfer and mixing on the card

The task of carding is by no means completed when the fibre tufts have been opened and the fibres separated. This is because the mixing of the separated fibres is still very important. Fibres are found on much of the clothed surfaces of the card, that is, there is a reservoir of fibres on the clothing. These fibres will eventually pass along the machine to the output web (unless they become embedded in the card clothing and must be removed by *fettling*).

The swift can be regarded as the fibre 'highway' on the card, with the workers providing detours and the doffer providing the exit (Figure 9.18).

Figure 9.18 The 'fibre highway' on a card. Source: Wood, 2006.



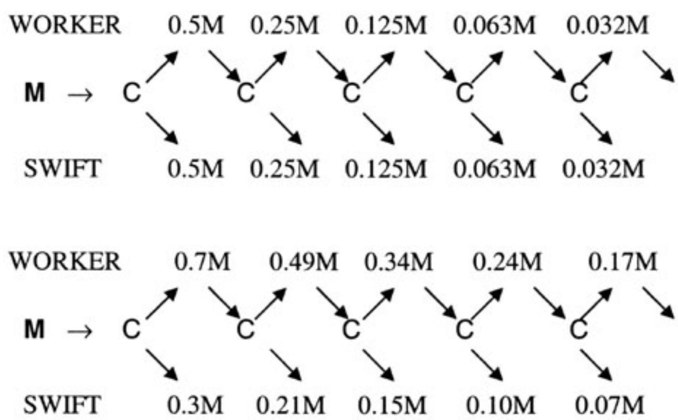
Collecting fraction of a worker

Mixing occurs because in each carding section the workers and the doffer capture a proportion of the fibres presented to them. The doffer collects about 20% of the fibres presented to it by the swift, while new fibres are continually being fed to the swift as it revolves. A worker diverts portions of the tufts that the swift brings to it, and the stripper returns the worker's share of fibre to the swift after some time (say, a few seconds) has elapsed. This provides an opportunity for these fibres to be mixed with fibres that have been on the swift for a longer or shorter time. A levelling action also occurs that depends on how the material is shared between the worker and the swift. The proportion of fibre captured by a worker is its *collecting fraction*. Its value is always between 0 and 1.

To illustrate the significance of a high worker collection fraction p, consider a worker that is set to run with a p-value of 0.5 and then changed to operate at 0.7 (Figure 9.19). M is the input fibre mass on the swift entering the working zone. Although with each revolution of the worker an equal mass will be retained, the diagram shows what happens to the first mass of fibre 0.5M removed from the swift and then fed back onto the swift within a short time, and a portion removed again by the worker. Five cycles are shown in the diagram.

For p=0.5 in the first cycle, 0.5M is removed by the worker leaving 0.5M to move forward on the swift. The 0.5M is subsequently stripped from the worker, to be returned to the swift and becomes mixed with new tufts and fibres entering the carding zone. In the second cycle, the worker will again remove 0.5 of the mass entering the carding zone; so 0.5 x 0.5M = 0.25M is now retained by the worker. For the third, fourth and fifth cycles, 0.125M, 0.063M and 0.032M respectively are retained.

Figure 9.19 Fibre diversion to worker on card, with collecting powers of P = 0.5 (upper) and P = 0.7 (lower). Source: Wood, 2006.



When the collecting power is 0.5, only 3.2% of the tuft travels around the worker 5 times. When the collecting power of the worker is increased to 0.7, a much larger proportion, 17% of the tuft, remains on the worker after 5 cycles.

Thus, the higher the collecting fraction:

(a) the greater the amount of carding a tuft will receive, and
(b) the higher the amount of mixing achieved.

The action between the swift and the doffer is essentially the same as that between a swift and a worker. Fibres approaching the doffer have a certain probability of being captured by the doffer wire and be removed from the carding unit. Hence the doffer collecting fraction, which is typically around 0.2, controls the period that a fibres cycle on the swift (and undergo further working actions) before being removed. Therefore the settings of the workers and doffer relative to the swift, as well as the speeds of the rollers, control the degree of mixing on the carding unit, or its ‘carding power’.

The collecting fraction of a worker depends on a number of factors – i.e. the characteristics of its clothing teeth, the gap between worker and swift, card production rate and the relative surface speeds of worker and swift. It is not possible to calculate the collection fraction from these factors; instead an estimate can be made by stopping a card, and removing and weighing the fibre load on each roller. The rotational speeds of the workers and swift must also be known.

Calculation of the delay factor

When a tuft of fibre enters a carding section (comprising a single swift with several pairs of workers and strippers) the time it takes to travel through to the end of the section depends on:

a) the minimum time every fibre takes to be carried straight through the section and under the doffer, and
b) the time for which the swift, workers and strippers hold a fibre before it is removed by the doffer variable.

The first time (component (a)) is essentially the time in which the fibres are carried around the doffer. The second time (component (b)) is variable because fibres are retained by the swift and workers for varying durations. The average of time (b) is called the *delay factor* of the carding section.

Consider equilibrium carding conditions, when, in one swift revolution, the weight of fibre fed into the section equals the weight of fibre being removed by the doffer. Under these conditions, the delay factor D is defined as L/I revolutions of the swift where L is the total load of workable fibres carried by the swift, workers and strippers, and I is the input to the carding section, per swift revolution

The longer the delay factor, the higher the level of mixing occurring in the carding section.

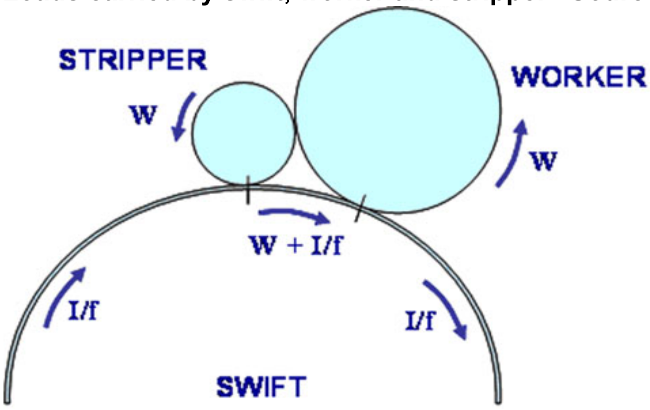
The term *workable* fibres refers to the fibres which ultimately appear as output; fibres lost as fly or trapped in the card clothing (fettlings) are excluded.

The following derivation of a mathematical formula for the delay factor D, may be omitted for the non-mathematically inclined.

The load of workable fibres on a simple card can be calculated in terms of the doffer collecting power f, the working collecting power p_1, p_2, p_3, etc, and the times n_1, n_2, n_3 etc. that the fibres are held by the workers. The collecting powers are usually small and hence any differences in the swift loading before and after the doffer are small and can be ignored for the purposes of this example.

Since the output per swift revolution is the same as the input I, the total load of workable fibres on the swift is I/f. Considering any worker, the weight of fibres returned to the swift surface by the stripper in a time equal to one swift revolution must be considered. When an equilibrium state of loading has been reached this is equal to the weight W taken up by the worker per swift revolution (see Figure 9.20).

Figure 9.20 Loads carried by swift, worker and stripper. Source: Wood, 2006.



If p is the collecting power of the worker (i.e. the fraction of the weight of fibres presented by the swift that is captured by the worker) then

$$P = W / (I/f + W) \text{ or}$$

$$W = I/f \times p/(1-p)$$

If fibres are held by the worker for n swift revolutions before being returned to the swift, the total load carried by the work is

$$nW \text{ or } I/f \times np/(1-p)$$

Thus the total load L carried by the section (swift and all workers) is:

$$L = I/f\,[1 + n_1p_1/(1-p_1) + n_2p_2/(1-p_2) + n_3p_3/(1-p_3) + \ldots]$$

where the subscripts 1,2,3,… refer to the first, second, third, etc.… workers.

The delay factor D = L / I, so for a carding part with three workers the delay factor is:

$$D = 1/f\,[1 + n_1p_1/(1-p_1) + n_2p_2/(1-p_2) + n_3p_3/(1-p_3)].$$

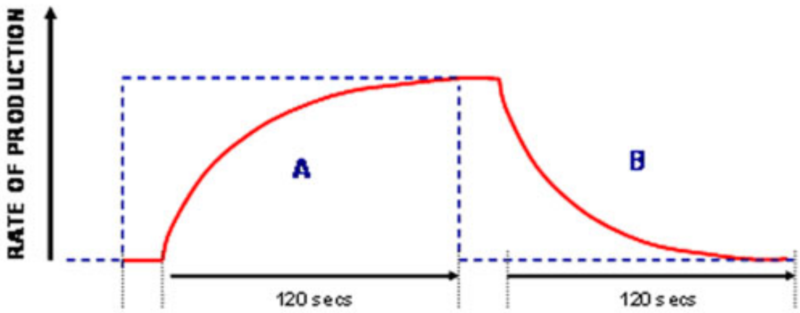
Maximum mixing can be achieved on a carding section when the delay factor is as long as possible. This may be achieved by:

- having a small doffer collecting fraction f, so that relatively few fibres are removed by the doffer in one swift revolution
- having worker collecting fractions p close to 1 (the workers capture most of the fibres presented to them)
- having slowly rotating workers (large n) so that a considerable time elapses before fibres removed by the workers are returned to the swift.

As the fibre mass moves through a carding section, it will have an increasing proportion of individual fibres aligned in the machine direction, and will be composed if increasingly smaller tufts. Therefore, the fibre mass on the swift will be less easily caught by downstream workers operating with the same machine conditions. In addition, as fibres on the swift pass by successive strippers, and the fibres from the worker are returned to the swift, the pressure between swift-stripper roller surfaces causes fibres to be pushed deeper into the swift clothing. This also makes it difficult for downstream workers to catch fibres. The action of the fancy before the doffer is to lift the fibre mass to the tips of the clothing teeth to enable easier fibre transfer to the doffer.

Figure 9.21 shows the smoothing effect of a card. If a constant feed rate of fibres to the carding unit is suddenly changed, then the rate at which fibres leave the unit at the doffer will not change at all for a certain time interval. When the output rate begins to change, it will do so only gradually until it reaches the input rate of feed. The relatively few fibres lost as fettlings or droppings can be ignored.

Figure 9.21 Response of varying the feed rate to a carding unit. Source: Wood, 2006.



The dashed rectangle represents the feeding of wool to a carding unit, with an abrupt start and abrupt stop. The graph shows that there is a delay of perhaps 10-20 seconds before the fibres reach the end of the unit. Curve A, which represents the output rate, rises rapidly when the first fibres arrive and levels off after about 120 seconds to a rate that is equal to the input weight. By this time all rollers on the unit, especially the workers, swift and doffer, are fully loaded with fibres and the normal production rate of the unit has been reached. This is a kind of equilibrium state.

Suppose at this instant, the feed to the unit is stopped. There is a delay once again of 10-20 seconds before the stoppage begins to be apparent at the output end (second short arrow). With no more fibre entering the card, the output feed drops away (curve B). After a further 120 seconds or so all the rollers have been stripped of fibres and there are virtually no more fibres remaining to reach the output.

The existence of a time lag between changes in input feed and output feed means that the clothing of the card is acting as a ‘reservoir’ of fibres. This reservoir effect, associated with a high delay factor, promotes good mixing. It also smoothes out fluctuations in feed rate to the card, perhaps due to inconsistent weighings of a feed hopper. If the delay factor is too high however (due perhaps to slow rotation of the doffer) the swift becomes overloaded, carding becomes inefficient and web quality deteriorates (with increased neps appearing).

The delay factor decreases as the doffer speed increases, but is not significantly affected by doffer setting or worker settings. Worker speeds have relatively little influence on the delay factor. Longer fibre blends tend to be associated with longer delay factors, i.e. they are easier to blend.

9.4 Nep formation

Nep formation is a downside of carding, along with fibre breakage and inadequate mixing. A nep can be described as a tiny knot of fibres which is not removed during carding, or may even be introduced during carding. Townend defines a nep as “any entanglement of fibres which cannot be separated by needles during the examination of a carded web, sliver or top” (Townend 1982).

Neps migrate to the surface of the yarn during spinning and affect the appearance of yarn and fabrics, limit the yarn count, increase the rate of end-breaks during spinning and contribute to the costs of mending and finishing. In worsted processing an important function of the comb is to remove neps.

Nep formation is influenced by fibre properties and carding conditions:

- Fine wools tend to produce more neps than coarse wools, so the occurrence of neps is more of a concern in fine wool carding than in the carding of carpet wool blends
- The production of neps tends to increase as the rate of production of a woollen card is increased (i.e. increasing the kg/hour). If the mat of wool fed to a card is too thick, the card wire cannot cope properly with the fibres; from this loss of fibre control, excessive nepping and fibre breakage are the likely results
- High nep counts also arise when wool is carded too dry or too wet – a range of 20-25% in regain is recommended when carding fine wools.

In the carding process the card wire performs the opening and mixing of the fibre tufts. Thus, wire parameters such as tooth density, fineness, profile, angle of bend and the type of foundation all have an effect on the quality of the carded web and hence yarn quality. To produce nep-free webs at high production rates:

a) it is necessary to ensure the circularity of rollers so that they can be set closely and accurately
b) the clothing should be appropriate to the fineness of the fibres being carded and the tooth density not be too low
c) the card wire must be sharp, specially on the doffer and workers, and
d) the doffer speed must be as high as possible (so that fibres do not spend an excessive time being recycled on the swift and hence become 'over-carded').

Readings

The following reading is available on CD:

1. Wool Science Review, 1952, The Scientist Looks at the Wool Industry: Carding, *Wool Science Review,* vol. 9, p.3.

Activities	Available on WebCT
Multi-Choice Questions	Submit answers via WebCT
Useful Web Links	Available on WebCT
Assignment Questions	Choose ONE question from ONE of the topics as your assignment. Short answer questions appear on WebCT. Submit your answer via WebCt

Movies

The following movie is available on CD:

Canesis Network Ltd. Woollen Carding.

Summary

Irrespective of which of the three routes is used to process wool into yarn, the card (or carding machine) plays an essential part. Although the design and operation of cards for woollen and worsted/semiworsted processing are quite different, the principles on which these machines operate are the same. Each machine uses the key actions of tuft opening, working, stripping, raising and doffing to convert the wool into a suitable form for the next stage of processing. In the process, fibre mixing occurs, but often at the expense of fibre breakage and nep formation in the fibrous web.

This topic outlines the functions of the key components of a carding machine, the mechanisms of fibre mixing and fibre breakage, and the conditions that encourage the formation of neps.

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Glossary of terms

Carding	A process carried out by a card (or carding machine). It involves opening clumps of wool, disentangling and mixing the fibres and the removal of vegetable matter as preparation for subsequent steps in yarn manufacture
Card section	A simple card (or part of a card), comprising a single swift and associated rollers
Clothing	The metallic teeth covering the surface of card rollers – may be flexible fillet wire or rigid metallic wire
Collecting fraction	The weight of fibre captured by a worker, as a ratio of the weight of fibre presented to it by the swift. It has value in the range 0 – 1. (Sometimes called the *collecting power*)
Delay factor	The average time a fibre takes to travel through a carding machine, or a carding section

Doffer	The final roller in a carding section which removes fibres from the swift and delivers them to the next stage
Doffer comb	An oscillating blade that removes the web of fibres from the doffer
Fancy	The card roller with long wire teeth that raises fibre embedded in the clothing of the swift, thus enabling more efficient removal by the doffer
Fettlings	Fibres embedded in the clothing of a card. These are unworkable fibres and must eventually be removed by fettling (suction or manually)
Fibre length	The distance between the ends of a fibre that is under slight tension to remove most of the crimp but not to produce any extension
Fillet	Flexible wire clothing comprising wire teeth mounted in a foundation of laminate fabric and rubber
Hooked fibres	U-shaped configuration at either end (or both ends) of a fibre; introduced in carding
Lickerin	The initial opening roller on a card – it receives tufts of fibre from the feed sheet and transfers them in partially opened form to the swift
Lubricating	Applying a processing oil (in a water emulsion) to wool prior to carding
Nep	A small entanglement of fibres that constitutes a fault in a carded product
Roller setting	The separation between two rollers, usually measured in mm or gauge
Sliver	A relatively thick strand of fibres in continuous form without twist
Slubbing	The strands of fibre from a woollen card that have been consolidated by the rubbing action of the condenser
Swift	The large, fast moving, central roller of a carding section
Web	A thin, fragile, uniform sheet of fibre held together by inter-fibre cohesion
Withdrawal force	The force required to remove a single fibre from a tuft of fibres
Workable fibres	Fibres on the card that are free and available to be manipulated, as opposed to the unworkable fibres (fettlings, fly and droppings)
Worker	The slowly rotating card roller that operates in conjunction with the swift to open the tufts of fibre – the working action