Fibre Dynamics in the Revolving-Flats Card
Part II

An investigation into the opening, individualisation, orientation and configuration of fibres during short-staple carding

A. Dehghani, C.A. Lawrence, M. Mahmoudi, B. Greenwood, C. Iype
School of Textile Industries, University of Leeds, Leeds, LS2 9JT, England
E-mail: a.a.dehghani-sanjj@leeds.ac.uk

Abstract

High-speed photography was used to investigate the state of fibres during the short-staple carding process. Image processing was employed to investigate the flow uniformity and the degree of opening and fibre individualisation of the fibre mass. The results showed that there is a considerable mass flow variation at the taker-in stage and at the back of the cylinder. Due to the carding action between the cylinder and the revolving flats, most tuftlets are separated into individual fibres, but some remain as micro tuftlets and are transferred to the doffer. With the increased discretisation the fibre mass becomes more uniformly distributed at the front of the cylinder. However, on the doffer the mass flow variation increases, which suggests that the transfer is not a uniform action. The angle of orientation of fibres was measured at the taker-in, at the front of the cylinder after the revolving flats and at the doffer stage. It was found that the fibres are highly orientated at the front of the cylinder. However, after the transfer region the degree of orientation of the fibres on the doffer decreases. In order to establish an understanding of the state of individual fibres, the change in the crimp level of fibres during the process was studied. It may be assumed that crimp level is directly related to the forces applied to the fibres. The results showed that the fibres at the front of the cylinder are subjected to more tension as compared to the fibres at the taker-in stage. A study was also carried out on the effect of the boundary layer around the cylinder by directly measuring the speed of individual fibres at the front of the cylinder. This study showed that the majority of the fibres are hooked to the cylinder wires and travel at the speed of the cylinder surface.

Introduction

Many studies have been carried out on the dynamics of the process of the revolving flats card and a critical review of the literature has been reported by the authors of this paper [1]. The literature review showed that research is still needed into some of the fundamental areas of the process, particularly concerning the change in the state of fibres within the system.

Besides the removal of impurities and the uniformity of the output of the process, primary issues in studying the carding process are *opening*, *individualisation* and *orientation* of fibres [2].

High-speed motion photography, specialised light sources and image analysis have gone through various advances [3]. The work reported here uses such techniques to investigate the degree of opening, individualisation and orientation of fibres at various stages of the carding process. The use of such advanced techniques has also made it possible to study some of the characteristics of fibres such as the change in the fibre crimp level and speed, which is related to the dynamic state of fibres. In the current work an objective method of analysis of the photographic images was employed and to minimise distortion to the fibre flow, only minor modifications were made to the card.

Experiment

Material

Russian cotton (Gork 98) was used for some of the experiments. Based on the HVI test results, the cotton had a staple length of 27mm, a uniformity value of 80 and micronaire value of 4.4.

Polyester fibres of 1.7dtex and 38mm length were also used. This included a blend of white and black polyester fibres. The black fibres were dope dyed to minimise the difference in surface characteristics of the fibres in the blend. The white fibres, which appeared black in negative on the films, were found to be better for analysis and were primarily used as tracer fibres (5%) in the current study.

Laps were made from the cotton and polyester fibres with an average weight of 590g/m^2 and also 260g/ m^2.

Card Specifications

A high-speed card was used for this work. Tables 1 and 2 give the relevant specifications and the manufacturer's recommended settings for the card. For the high-speed photography the following modifications were carried out on the carding machine. In order to provide a reasonable contrast between the white fibres and the background, a section of taker-in, cylinder and doffer was painted matt black. At the pre and post carding stages on the cylinder, one of the fixed flats was replaced with a flat bar in which a window was made.

Table 1: Specifications of the carding machine

Roller	**Diameter** (m)	**Speed**		**Wire specifications**			
		Revs (r min^{-1})	Linear (m min^{-1})	Point density (in^{-2}, cm^{-2})	Effective height (mm)	Front Angle (°)	Pitch (mm)
Feed	0.1	2.8	0.88	-	-	-	-
Taker-in	0.254	752	600	42, 6.5	3.94	90	4.8
Cylinder	1.016	505	1611	860, 133.3	0.55	63	1.5
Doffer	0.508	31.2	49.8	378, 61.7	2.4	60	1.8
Flats:							
Revolving	-	-	0.16	370, 57.4	4.6	75	-
Fixed (back)	-	-	-	93, 14.4	-	-	2.4
Fixed (front)	-	-	-	542, 84	-	-	1.3

Table 2: Settings of the carding machine

Components	**mm**	**inch**
Feed plate to taker-in wire	1.0	0.040
Taker-in to cylinder wire	0.18	0.007
Back fixed flats to cylinder wire	0.97	0.038
Revolving flats to cylinder wire	0.25	0.010
Front fixed flats to cylinder wire	0.18	0.007
Cylinder to doffer wire	0.13	0.005

High- Speed Camera

A Photech 16mm rotating prism camera with a Mamiya 645 Macro C 80mm f/4N lens was used. The camera was capable of recording up to 10,000 pictures per second full frame and 20,000 pictures per second half frame. For the purpose of the investigation, speeds of 5000 and 10,000 pictures per second were employed. Ilford HP5 400ASA 100ft and 400ft roles were used for the framing rates of 5000pps and 10000pps respectively.

A digital video camera was also used for the work. This system was a Kodak HS Model 4540 capable of 4500 frames per second recording speed. The sensor resolution of this camera was 256×256. The system has a split mode in which the speed can be increased up to 40500 pictures per second, but the resolution is reduced proportionally. The speed and resolution used in the current work were 9000 pictures per second and 256×128 pixels respectively. A TV 80mm lens was found to give the required fibre image quality for subsequent analysis.

The trials carried out using both high-speed cine and digital video cameras showed that for experiments with polyester fibres, the cine camera provided better results, whereas the digital video camera was found to give better images of cotton fibres.

Light Source

The linear speed of the card cylinder was of the order of 30m/sec. At a film speed of 10,000 pictures per second the exposure time would be 100µSec during which fibres attached to the cylinder surface move a distance of 3mm. To avoid a blurred image a 10W pulsed laser light source (Copper Vapour LS10-10) was used for the work. This provides a laser light in the yellow/green region (510-580µm) of the spectrum with pulse duration of 25nsec (i.e. a fibre movement of 0.75µ), and via fibre optic delivery gave suitable illumination through small access areas.

High-speed photographic observations

Figure 1a shows the positions where photographic observations were made and Table 3 gives the camera and light source settings. Figure 1b provides a series of motion pictures of the carding process using 100% cotton fibres, which can be viewed by following the instructions given in the figure. These are snap shots of images from: A - taker-in, B - cylinder, back immediately after transfer, C - cylinder, back after one fixed flat, D - cylinder, front after revolving flats, E - cylinder, front after three fixed flats, F - Under the cylinder, and G - under the doffer.

A. Taker-in

A study of the sequence of the shots showed that the taker-in opens the lap into individual fibres and tuftlets in proportion of almost 50/50. An analysis was carried out to determine the size distribution of tuftlets and the classification of the tuftlet shapes. The results are reported elsewhere [4]. It was found that the tuftlets were highly orientated in the machine direction, 70% of them had an angle of orientation of 5 degrees with respect to machine direction. About 50% of tuftlets had lengths between 10-20mm, widths between 2.5-5mm and length-to-width ratios of up to 3.

B. Cylinder back

The analysis showed that on transfer the fibre mass (tuftlets and fibres) was drafted (draft of about 2.7), the tuftlets were elongated and more orientated. About 50% of tuftlets had a length-to-width ratio between 3 to 6. The analysis of the degree of orientation showed a 10% increase in the alignment.

C. Cylinder back

The films taken indicated that tuftlets break down between cylinder and fixed flats. When a tuftlet is caught between the cylinder and the fixed flat, it is parted, a fraction being carried forward and the rest remains in the flat as hanging fibres until they are removed by the cylinder. It was found that the number of tuftlets per unit area decreased by an average of 60%.

D and E. Cylinder front

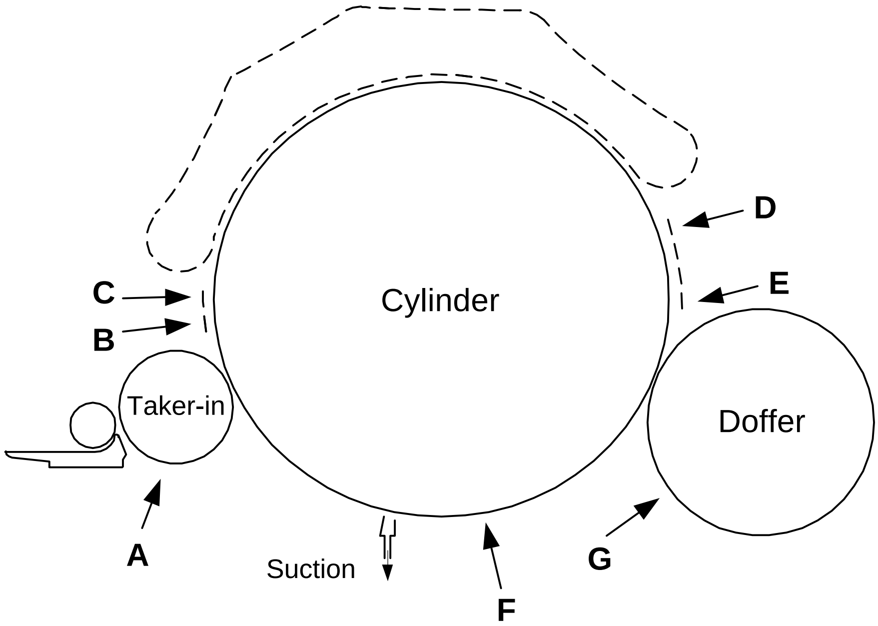
At this stage the fibres are largely individualised with the occasional micro-tuftlets present. After the fixed flats very few micro-tuftlets were observed. Analysis of the fibre configuration and dynamics is considered in the results and discussion section.

F. Under-Cylinder

The observations showed that a significant amount of fibres remained on the cylinder and included among the fibre mass were micro-tuftlets, however at this stage it was not possible to quantify the fibre mass from the photographs taken.

G. Doffer

After the cylinder-doffer transfer point fibres appear to have lost their alignment in the machine direction and are unevenly distributed, with evidence of loose groups of fibres and in some cases neps. Again the results of the analysis are given in the results and discussion section.



a) Positions for high-speed photographic observations

A. Taker-in

B. Cylinder back

C. Cylinder back

D. Cylinder front

E. Cylinder front

F. Under cylinder

G. Doffer

b) Typical video clips of the observations (Click on position buttons A, B, …,G)

Figure 1: Schematic of carding machine and typical high-speed photographic observations of 100% cotton fibres.

Table 3: Camera and light source set-up

Card Position	Lens			Viewing area (mm)	Light position
	Focal length (mm)	Ext. tube (mm)	f		
Taker-in	80	50	16	10 x 10	Side
Cylinder, back, before fixed flat	80	80	8	10 x 5	Above
Cylinder, back, after fixed flat	80	80	8	10 x 5	Side
Cylinder, front	80	80	8	10 x 5	Above
Under the cylinder	(zoom)	30	16	10 x 5	Side
Under the doffer	80	80	16	10 x 10	Below

The experiments were carried out with the card settings as shown in Table 2 and after 10 minutes running from start-up. The atmospheric conditions were 25°C and 47% RH. When photographing the fibre mass on the back of the cylinder a suction unit was mounted in the position shown in Figure 1a. This was employed to ensure that the recycling layer [1] was not part of the observations so that the change in the fibre mass flow directly after transfer from the taker-in to the cylinder could be analysed.
With the cine camera, for each high-speed photographic observation, 3000-12000 frames were recorded. In the case of video camera 3000-6000 frames were recorded onto videotape in analogue form and later digitised for analysis.

The films from the cine camera were analysed on a computer linked NAC film motion analyser Model 160F. The Movias motion analysis package used for this work provided a number of facilities to analyse position and velocity of the fibres.

The digitised films, taken by the high-speed video camera, were analysed using the 'Image-Pro plus' image processing package to determine opening and individualisation and angle of orientation of fibres.

Method of Analysis

Opening and Individualisation

Photographic observations showed that the mass flow was not uniform, variations were seen at different points. Assuming a uniform feed, this variation can happen as a result of some tuftlets not being opened by the wire action of the process. If this variation is quantified, it provides a means of measuring the degree of opening and individualisation at the different stages of the carding process. At any observation point during carding, if the degree of opening is constant then the fibre mass flow passing this point should be uniform.

Utilising laboratory test methods for direct assessment of opening of the fibre mass and fibre individualisation at the various stages of the carding process is very difficult. However, with image analysis techniques a method was developed to objectively assess the degree of opening and individualisation.

The high-speed photography provided a continuous sequence of images (i.e. frames of the film) of the fibre mass flow at various points of observation during the carding process. This was in effect an on-line monitoring of the fibre mass flow where the analysis of the images was subsequently carried out off-line.

Each digital image includes pixels with grey level values between 0 to 255 (black to white). Near black areas in the images correspond to the surface of the carding rollers and near white areas correspond to fibres. Therefore, if the flow is uniform, the differences between the average pixel grey levels of successive images in the sequence on a film should be very small. On the other hand, non-uniformity as a result of poor opening and individualisation should show as high variations of the average pixel grey level for the sequence of images. Since the degree of opening and individualisation should directly correlate with the uniformity of fibre mass flow, the average pixel grey level variation should inversely correlate with the degree of opening and fibre individualisation. This variation was therefore used to assess the degree of opening and fibre individualisation at the different stages of carding.

Fibre Orientation, Crimp, configuration and Speed

Using the image-processing package, the angle of orientation of fibres chosen at random from a sequence of images, was determined with respect to the machine direction.

Crimp values, based on the number of crimps per unit length, were not easily measured for various stages of the carding process. At the taker-in stage, the full length of individual fibres could not be traced in the sequence of images obtained, as they were embedded within fibre clusters or tuftlets. However, it was considered adequate to measure the crimp cycle length for segments of fibres projecting from tuftlets. For comparative purposes this would give a reasonable indication of relative crimp changes, which could be attributed to forces acting on the fibres during carding.

The forces applied to individual fibres may well be different at various stages of carding. At the taker-in stage the degree of individualisation is lower than that at the front of the cylinder where the fibres are in an individual state. When the fibres are in the form of clusters or tuftlets, the forces are mostly applied to the clusters or tuftlets rather than individual fibres. These forces can not be directly determined however their effect can be realised by studying the change in the state of individual fibres. Since fibres are directly influenced by pulling forces of the wire clothing and the air current in the boundary layer near the moving carding surfaces, the fibre crimp should be altered. The average crimp level should be lower if the influencing forces are smaller or if the fibres are locked in a larger body such as a tuftlet.

In order to determine the fibre speed, the co-ordinates of ten points on a single fibre were found in a sequence of frames showing the movement of the fibre. These co-ordinates were compared with the co-ordinates of the wires in the same image sequence. Since the filming speed was known, the fibre speed could be calculated using the distance travelled by the fibre.

In the above analysis the effects of three parameters on the configuration of the individual fibres at front of the cylinder were investigated. These parameters were lap weight, the total mechanical draft of the machine and the setting of the plate which was used in place of the first fixed flat at the front of the cylinder.

Results and discussion

Fibre Opening and Individualisation

The coefficient of variation of the mean pixel values for a sequence of frames at the four key positions in the carding is given in Table 4. These, as mentioned earlier, provide a relative measure for the degree of opening and individualisation at the different positions.

Table 4: CV% as a measure for degree of opening and individualisation

Card Position	Mean Pixel values	CV%	95% confidence intervals
Taker-in	82.9	15.4	82.3 - 83.6
Back of cylinder after transfer	70.8	17.8	70.5 - 71.2
Front of cylinder after revolving flats	156.7	6.5	156.4 - 157.0
Doffer	64.1	9.9	63.4 - 64.9

The images at the taker-in stage showed that a considerable degree of opening and individualisation takes place at this stage. However, there was still a large number of tuftlets and fibre clusters present in the fibre mass flow resulting in a CV% of 15.4. At the back of the cylinder this value increased to 17.8, which may be due to the draft of the material when it is transferred to the cylinder. At the front of the cylinder the CV% was reduced to 6.5, which indicates that the fibres are more open, and more uniformly distributed on the surface of the cylinder. The CV% at the doffer stage increased to a value of 9.9. Considering the doubling action at this stage, this higher value suggests that the transfer of fibres between the cylinder and the doffer is not a uniform action (Figure 2).

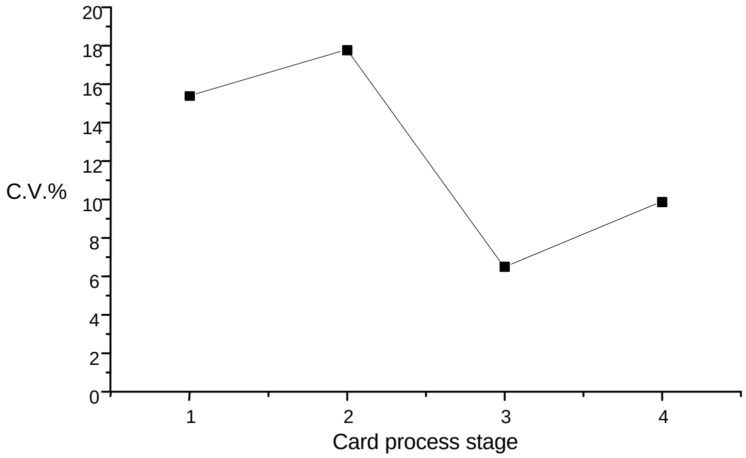


Figure 2: Fibre flow CV% as a relative measure of degree of opening and individualisation
1- Taker-in, 2- Back of cylinder, 3- Front of cylinder, 4- Doffer

Fibre Orientation

The angle of orientation of fibres was measured on the taker-in, the front of the cylinder and on the doffer. Table 5 gives the measured values and Figure 3 shows the distribution of the angles of orientation at these three positions. The mean angle of orientation on the taker-in was 13 degrees with respect to the direction of fibre flow. At the front of the cylinder after the revolving flats, the mean angle of orientation of fibres was reduced to 4.5 degrees. This shows that most fibres at this stage are nearly parallel to the machine direction. After the cylinder-doffer transfer region the angle of orientation of fibres increased to 19.5 degrees, which suggests that during the transfer, the orientation of fibres deteriorates. The statistical analysis given in Table 5 shows that the differences are significant at 99% confidence limits.

Table 5: Fibre angle of orientation during the carding process

Card Position	**No. of Samples**	**Mean (Deg.)**	**Range (Deg.)**	**Std. Dev.**	**CV%**	**Std. Err.**	**99% confidence intervals**
Taker-in	500	12.92	0 - 68.2	10.19	78.9	0.46	11.74 - 14.10
Cylinder, front	500	4.61	0 - 20.1	3.61	78.3	0.16	4.19 - 5.03
Doffer	500	19.47	0 - 73	14.40	74.0	0.64	17.81 - 21.14

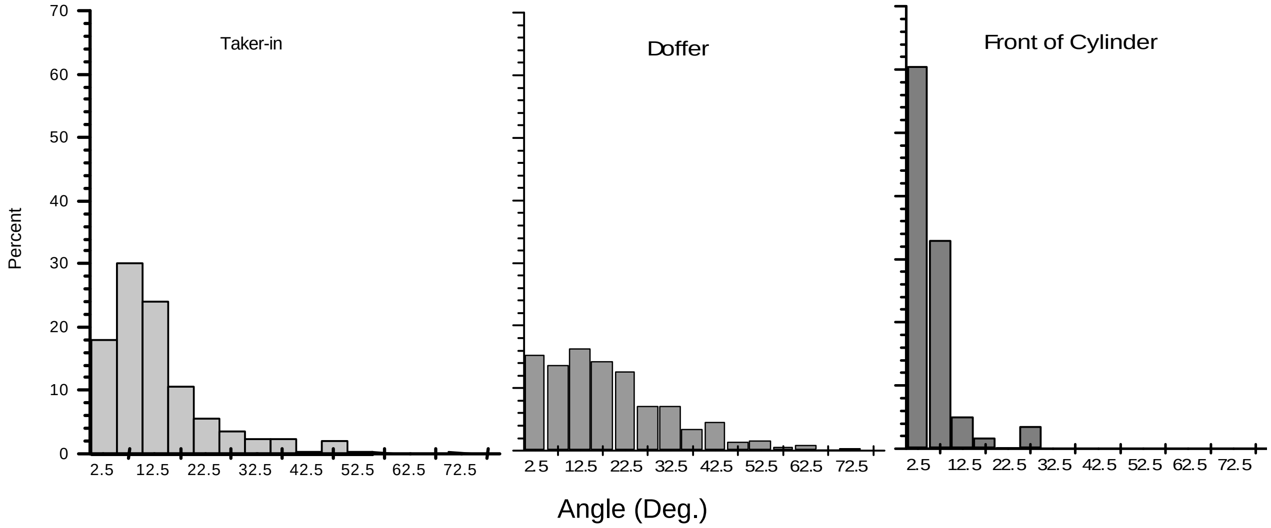


Figure 3: Distributions of fibre angle of orientation at taker-in, cylinder and doffer

Fibre Crimp

Crimp cycle length measurements were carried out at the taker-in and the front of the cylinder. Table 6 gives a summary of the results obtained. The distributions of the crimp cycle length at these two positions are shown in Figure 4. As the figure illustrates, both distributions are skewed and there is a clear difference between the skewness. Table 6 shows that the average crimp cycle length at the front of the cylinder is greater than that at the taker-in stage. This suggests that the individual fibres must be under a high tension at the front of cylinder.

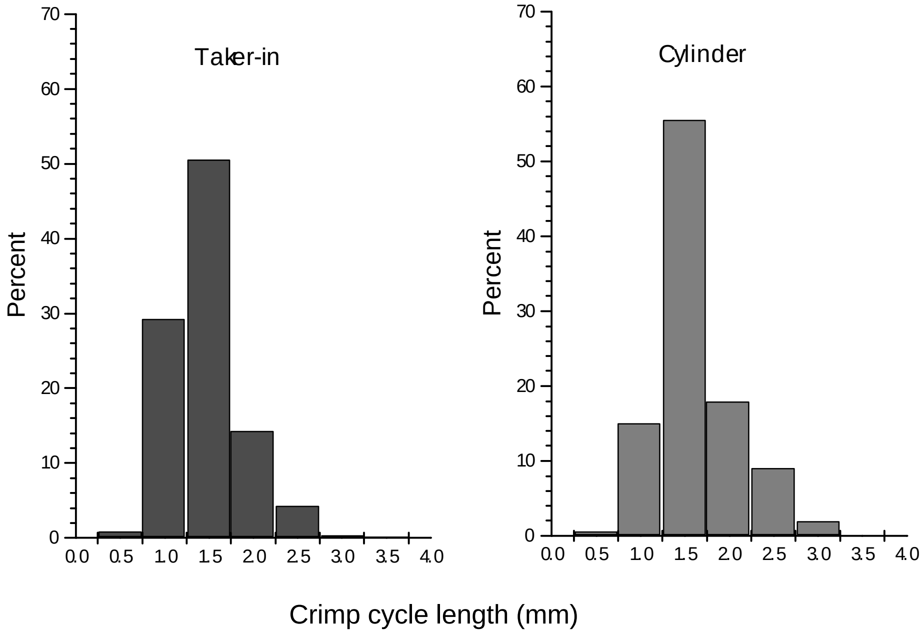


Figure 4: Distributions of fibre crimp cycle length at taker-in and front of cylinder

Table 6: Fibre crimp cycle length at two stages of carding process

Card Position	No. of Samples	Mean (mm)	Range (mm)	Std. Dev.	CV%	Std. Err.	99% confidence intervals
Taker-in	500	1.27	0.4 - 3.3	0.398	31.3	0.018	1.224 - 1.316
Cylinder, front	500	1.427	0.5 - 2.9	0.427	29.9	0.019	1.378 - 1.476

Fibre Configuration

Using tracer fibres, the configuration of individual fibres at the front of the cylinder was studied for both cotton and polyester. For both fibre types, as would be expected, the great majority of tracer fibres observed were in the individual state. The configuration and speed of the individual fibres were determined. There were very rare occasions where a small cluster of fibres could be seen as well. From examination of the configuration of fibres, three categories were identified: unhooked fibres and hooked fibres, which were further classified as middle hooked and leading hooked. No trailing hooked fibres were observed. To identify middle hooked fibres; the length of fibres was divided into three equal divisions. If the fibre was anchored by the wire in the middle part, it was classified as middle hooked.

The results of this study are given in Table 7. It should be noted that the percentages in this Table refer to the number of fibres for each configuration from the total number of observed individual fibres. As the Table shows, in the case of cotton fibres up to 77% of the individual fibres were hooked to the cylinder wires. In the case of polyester fibres, between 89 to 96 percent of the individual fibres were hooked to the cylinder wires. The results indicated that the change in the parameters such as lap weight, carding draft and the plate setting did not have any major effect on the percentage of the hooked fibres. Comparison of the middle hooked and leading hooked fibres show that, in general, a majority of hooked fibres are anchored by the wires from the middle section of the fibre.

Table 7: Configuration of individual fibres at front of the cylinder

Type of fibres	Lap weight (g/m^2)	Carding draft	Setting (in)	Fibre configuration		
				Hooked (%)		Unhooked (%)
				Middle	Leading	
Cotton	590	82	0.034	77		23
Polyester	590	82	0.034	96		4
	590	**175***	0.034	89		11
	260	175	0.034	56	38	6
	260	175	**0.007**	49	46	5

* Bold figures refer to the changed parameters

Fibre Speed

To analyse the speed of individual fibres at the front of the cylinder, the films taken at 10000 pictures per second using polyester fibres and with the setting of front plate at 0.034 inch, were used. The results of the analysis showed that all the fibres, which were hooked to the cylinder wire, were travelling at the same speed as the cylinder linear speed. The majority of unhooked fibres had also the same speed as the cylinder liner speed. However, there were a few unhooked fibres which had a speed about 10% lower than the linear speed of the cylinder. These fibres were considered to be travelling in the boundary layer.

Conclusions

An objective method was developed to assess the degree of opening and individualisation during short staple carding. The method uses high-speed photography and image analysis and is based on measuring flow variation in the carding process. It was found that at the take-in stage the fibres are both in individual and tuftlet forms and hence show a relatively high degree of flow variation. When the fibres are transferred to the cylinder, the flow variation increases possibly due to drafting between the cylinder and the taker-in. The flow variation is a minimum at the front of the cylinder, after the fibres have gone through the carding action between the cylinder and the revolving flats. This is due to the fibres being individualised and more uniformly distributed over the cylinder surface. On the doffer the flow variation increases again which suggests that the transfer action is not uniform.

The study of fibre orientation on the taker-in, at front of the cylinder and on the doffer showed that the fibre orientation significantly improves from the taker-in to the front of the cylinder. However, the degree of orientation deteriorates after the fibres are transferred to the doffer. The fibre crimp, configuration and speed were also studied. The results indicated that fibres at front of the cylinder must be under more tension as they have longer crimp cycle length. The study also showed that at the front of the cylinder, the majority of fibres remain hooked by the cylinder clothing. Polyester fibres showed considerably more hooked fibres as compared with cotton fibres. At this position fibres had the same linear speed as the cylinder surface. Some of the unhooked fibres, however, showed about a 10% lower speed and were considered to be travelling in the boundary layer.

This research work showed that whilst there is a significant improvement in fibre flow distribution, fibre opening and individualisation, and fibre orientation; as the fibre mass passes through the taker-in and the cylinder-revolving flat actions, there is a significant deterioration specially in fibre distribution and fibre orientation after cylinder-doffer transfer. Further development work concerning the cylinder-doffer transfer is therefore needed in order to improve short term regularity of the fibre mass for subsequent down stream drafting processes.

Acknowledgement

The authors wish to acknowledge the EPSRC for the funding of this project and EPSRC Instrument Loan Pool for providing the equipment. We would also like to thank Mr. D. Baker for his technical support.

References:

1. Lawrence C.A., Dehghani A., Mahmoudi M., Greenwood B., Iype C., 'Fibre Dynamics in Revolving-Flats Card', Part I, Literature Review, Autex Research Journal, Vol 1, No 2, pp 64-77 (2000) URL: www.autex.org/v1n2/2276_00.pdf
2. Byerley, W. G., 'Manual of cotton spinning', Carding, (3), The Textile Institute and Butterworths, England, (1965)
3. Ray, F. S., 'High-Speed Photography and Photonics', Focal Press, Oxford, England, (1997)
4. Dehghani A., Lawrence C.A., Mahmoudi M., Greenwood B., Iype C., 'Fibre Dynamics in Revolving-Flats Card - An assessment of changes in the state of fibre mass during the early stages of the carding process.', Journal of The Textile Institute (accepted paper), (2000)