The Effect of the Sliver Fiber Configuration on the Cotton Inter-fiber Frictional Forces

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ABSTRACT

Fiber surface properties have a significant effect on yarn spinning. The frictional behavior of fibers greatly influences their processing, their performance and the performance of the final product. In order to investigate the effect of fiber surface properties and inter-fiber friction during spinning process, card slivers are taken and subjected to three drawing passages. Card and drawing frame slivers are then tested by the Static Friction Tester (SFT), which has been developed earlier. Fiber fineness, maturity and fiber length are measured by using different testing instruments. Hook content is calculated by utilizing fiber length data. The statistical analysis of results shows the same trend for the different cotton fibers tested.

Keywords: Fiber, Sliver, Friction, Hook

INTRODUCTION

Fiber properties, their processing and the performance of end product are greatly affected by the frictional behavior of the fiber assemblies. The importance of friction has led to extensive research about the nature of friction, its impact on textile processing, and its role in determining yarn and fabric properties. The surface structure and the properties of fiber have an effect on fiber friction. The fibers are subjected to different forces during the spinning process. The most important of them, which plays a very important role, are cohesion and frictional forces. Friction forces are very important in determining the behavior of the fiber during processing, and they may also help in controlling the fiber flow. Different scientists have tried to calculate fiber friction by using different methods; work has also been done to calculate the effect of fiber friction on yarn strength and other tensile properties.

Before being processed, cotton fibers form small tufts, which are entangled to a certain extent. After the blow room, the fibers are subjected to wired surfaces during the carding process which individualizes the fibers. The fibers are very crimped and form hooks. The tendency of hooks is very asymmetric; the trailing hooks are mostly found as explained in detail by different researchers. [1-2] The card slivers are then subjected to the drawing process whose aims are essentially sliver CV% reduction, the fiber alignment, and hook opening. It seems likely that crimp and hooks affect fiber interaction.

The frictional forces define sliver strength and, up to a certain level, also yarn strength. Fiber to fiber friction and fiber to other surface friction is determined by the fiber material, fineness, crimp, and convolutions of cotton fiber. [3] The factors affecting inter-fiber friction can be divided into two groups: factors affecting the morphology of contact and factors affecting the mechanical properties of junctions. The first group includes the nature of the fiber surface, such as the cross sectional shape, the presence of convolutions, crimp and scales, and the contact made during testing (point contact, line contact and area contact). The second group includes the chemical and physical structure of the fiber. [4] Basu *et al*. [5] used single Egyptian cotton fiber and a straight probe under different loads to calculate the frictional forces. The withdrawal of a single long fiber from a tuft of compressed fibers has been used by Postle and Ingham. [6] The measurement of the frictional force between two fibers twisted together has been carried out by Lindberg in order to see how the fibers behave during the process when they are entangled with each other. [7] The development of frictional force during the relative motion of two identical fiber fringes has been studied by Lord [8] and later by El Moghazy. [9-10] Howell and Mazure conducted a theoretical study to explain the friction phenomenon. [11-12]

Inter-fiber friction affects the drafting force developed during the drawing process. The drafting force has been measured for cotton and rayon. [13-15] The results show that frictional force is affected by different drawing process parameters such as draft, input sliver count, sliver compactness, sliver direction, distance between the drafting cylinders, roller speed and fiber length. More precise results were obtained by using the device of Martindale with the help of a force sensor. [16] An excellent theoretical work has been carried out that explained the drafting force and fiber behavior during drafting. [17-18] A new device to measure fiber to fiber friction has been developed recently, called the SFT-Static Friction Tester. It measures the resistive force to breaking sliver under constant load to a pulling force with constant speed. [19]

This research was conducted to determine how the fiber configuration would affect inter-fiber friction during the drawing processes.

METHODS AND MATERIALS

In the present study, an SFT device was used to estimate the evolution of inter-fiber friction as the fibers are processed during several drawing passages. As described by Nowrouzieh *et al,* [19] this device "is composed of two identical carriages *Figure 1*. One of them (A) is fixed, whereas the second (C) is moving through a linear guide (B). A piece of sliver is put down in the channel of the two carriages which are initially in zero gage position. The sliver is compressed with the upper carriage sides (D) where two identical weights are loaded. The moving one is tracked with a constant speed, whereas the fixed one is attached, by the intermediate of a force sensor, to the frame. The distance between the two carriages is measured by a displacement sensor."

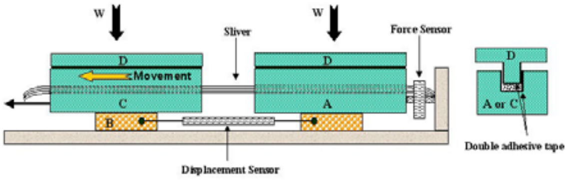


FIGURE 1. Static Friction Tester. [19]

The SFT gives the force-displacement curve as shown in *Figure 2*.

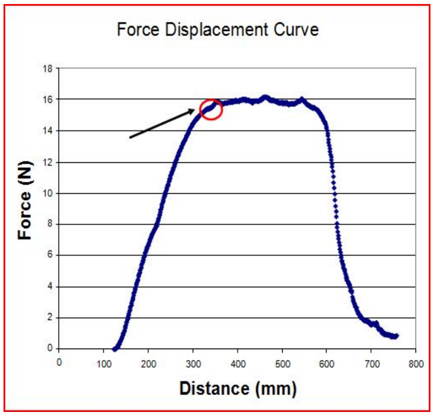


FIGURE 2. Force Displacement Curve.

The force required to break the sliver is plotted against the distance travelled by the moving carriage. The distance is plotted against the x-axis and is given in millimetres; the force is plotted against the y-axis and the value is given in Newtons. The force increases with the distance up to a certain level; after which the force decreases because the force applied to the sliver crosses the maximum resistive force. By analyzing this curve, the value of force is noted at the point where all the fibers are contributing against the applied pulling force to break the sliver.

The data obtained from SFT gives rise to Eq. (1) [19] to obtain the inter-fiber friction results:

$$F/N_F = k\,(W/\,N_F)^a \qquad (1)$$

where:

F is the frictional resistance force,
N_F is the number of fibers in the sliver cross section,
W is the perpendicular compression force on the fibers, and *K*, and *a* are the coefficients that characterize friction.

Three variables were selected: the type of cotton, the load applied perpendicularly on the sliver and the fiber stage during the process, namely, carding, and 1st, 2nd and 3rd drawing passages. The four different kinds of cotton card slivers were purchased from local market, there was no exact information available about their variety name and origin of production, but they were tested for fineness and maturity.. The results are discussed in the Results and Discussion section. The loads applied on both carriages of the SFT were 2000, 3000, 4000, and 5000 grams. The samples were tested six times for each of theses loads. The friction coefficients *k* and *a* were then calculated for each cotton at each processing stage using Eq. (1). The use of different process slivers and different types of cotton helped to evaluate the effect of sliver structure on its frictional behavior. The carded slivers were subjected to three drawing passages, keeping draft setting constant.

In order to minimize some blocking nuisance effects (the nuisance factors might be the specific operator which prepared the treatment, the time of day the experiment was run, and the room temperature), the testing order was completely randomized with respect to load and the process. The same procedure was carried out for each type of cotton.

The samples were kept for 24 hours under controlled conditions. The conditioned samples were tested for sliver count, fineness, maturity, length and inter-fiber friction. The sliver count was measured by using 5 m of sliver weighed on a simple scale. The fineness and maturity was measured by using Maturity meter I.T.F.-Lhomargy (ISO standards: ISO 2403 and ISO 10306).

To measure the fineness and maturity, ten samples were collected from each type of cotton. The machine was properly calibrated before each measurement. After calibration, 5 grams of fiber were taken for measurement. The sample was placed in the chamber. A low pressure P_1 was applied on the sample. The height of mercury H_1 and H_2 noted and the difference of H_2-H_1 gave the Micronaire Index (MI) by using a table provide with the instrument. Subsequently, the sample was subjected a second compression P_2, which was higher that the previous pressure applied. Again, the difference was noted, also the Maturity Index was calculated from the table. The value of MF% (percentage of mature fiber) was noted from the table. Shirley Maturity ratio (SMR) and the count (dtex) of a single fiber (T) was calculated by using the following formulae:

$$SMR = 1.76-\sqrt{(2.44-0.0212 * FM\%)} \quad (2)$$

Where $T = (3.86*MI^2 + 18.16*MI + 13) / (100 * SMR^2)$ (3)

The Micronaire index (MI), the maturity ratio (MR) and the percentage of mature fibers (MF%) are defined as follows:

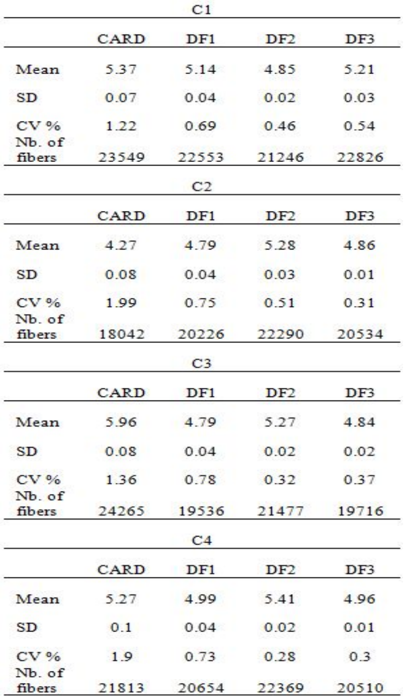
- MI - Micronaire Index: In practice, we define the fineness and maturity by a complex called Micronaire index (MI). However, one must be cautious about interpreting the results of MI, knowing that for the same Micronaire, it is possible to have different maturities since the finesse is a component.
- SMR - Maturity Ratio: The ratio of maturity that combines the percentage of normal and dead fibers.
- MF - the mean percentage of mature fibers.

The length of fiber was calculated by using an Almeter Peyer device. The fiber hook content was measured by carrying out this test in three different ways: the sample was prepared by laying the sliver in fiber sampler in the direction as it left the machine (trailing hooks will be opened), in the reverse direction (leading hooks will be opened) and also reversing the output fiber fringe and putting it in the fiber sampler (both types of hooks will be opened). The relative difference in length between hooked and aligned fibers allowed the evaluation of the hook content.

RESULTS AND DISCUSSION

The sliver count, fiber fineness and maturity results were analyzed statistically. The results of sliver count are given in the *Table I.* This table also shows the number of fibers within the cross section which is calculated by using the sliver count divided by the single fiber count (which is calculated using values of MI & SMR).

TABLE I. Sliver Count (kTex) and Number of Fibers in Sliver Cross Section.



C1

	CARD	DF1	DF2	DF3
Mean	5.37	5.14	4.85	5.21
SD	0.07	0.04	0.02	0.03
CV %	1.22	0.69	0.46	0.54
Nb. of fibers	23549	22553	21246	22826

C2

	CARD	DF1	DF2	DF3
Mean	4.27	4.79	5.28	4.86
SD	0.08	0.04	0.03	0.01
CV %	1.99	0.75	0.51	0.31
Nb. of fibers	18042	20226	22290	20534

C3

	CARD	DF1	DF2	DF3
Mean	5.96	4.79	5.27	4.84
SD	0.08	0.04	0.02	0.02
CV %	1.36	0.78	0.32	0.37
Nb. of fibers	24265	19536	21477	19716

C4

	CARD	DF1	DF2	DF3
Mean	5.27	4.99	5.41	4.96
SD	0.1	0.04	0.02	0.01
CV %	1.9	0.73	0.28	0.3
Nb. of fibers	21813	20654	22369	20510

The results in *Table I* are based on 10 repetitions. The DF1, DF2 and DF3 refer to 1st, 2nd and 3rd drawing passage respectively. In the table, the standard deviation is noted by SD and the coefficient of variation percentage is noted by CV%.

The results of fineness and maturity are shown in *Table II.*

TABLE II. Fineness, Maturity and Single Fiber Count (dTex).

	C1			C2		
	MI	SMR	T	MI	SMR	T
Avg.	4.44	0.86	2.28	4.25	0.82	2.37
SD	0.09	0.02	0.10	0.09	0.01	0.11
CV %	1.96	2.14	4.40	2.10	1.57	4.64

	C3			C4		
	MI	SMR	T	MI	SMR	T
Avg.	4.51	0.84	2.45	4.32	0.82	2.42
SD	0.03	0.01	0.04	0.06	0.01	0.06
CV %	0.67	0.76	1.57	1.28	0.89	2.46

Ten repetitions were performed. The standard deviation and CV% indicate that there were no considerable differences between these cottons. The single fiber count (T) was calculated from Micronaire index (MI) and Shirley Maturity Ratio (SMR).

The resistive force along with other calculated values were analysed statistically. A regression analysis was applied and a line fit was applied on the data for all the processes separately. The line fit gave the value of Ln*k* and *a* for each process.

Figure 3 shows the line fit for the regression analysis applied on the values of the cotton type C2 for the 1st drawing passage DF1.

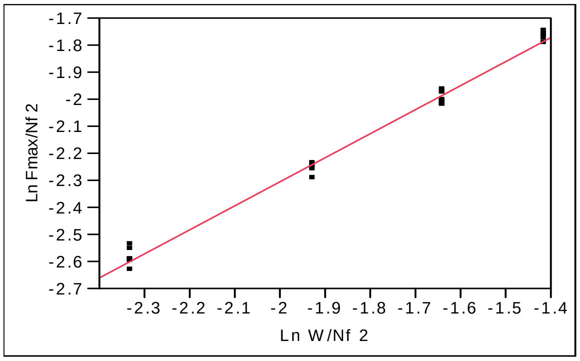


FIGURE 3. Line Fit regression analysis DF1 for Cotton 2.

TABLE III. Values of *a* and Ln*k*.

	C1		C2	
Process	Ln*K*	*a*	Ln*K*	*a*
Card	-0.58	0.83	-0.60	0.82
DF1	-0.53	0.89	-0.53	0.89
DF2	-0.57	0.88	-0.60	0.85
DF3	-0.60	0.89	-0.66	0.84

	C3		C4	
	Ln*K*	*a*	Ln*K*	*a*
Card	-0.57	0.84	-0.62	0.82
DF1	-0.52	0.89	-0.58	0.88
DF2	-0.55	0.88	-0.59	0.88
DF3	-0.64	0.85	-0.64	0.87

Table III shows values of *a* and Ln*k* for all four types of cotton tested for each step of the process i.e. the carding and the three drawing passages. The C1, C2, C3 and C4 are referred to 1st, 2nd, 3rd and 4th cotton respectively. In *Figure 4*, these values are plotted against the process only for cotton 2. The graphical representation of process against *a* shows that the value of *a* increases dramatically for the first drawing passage, but for the second and third drawing passage there is slight decrease in the value of *a*. The process and Ln*k* graph also show the same trend.

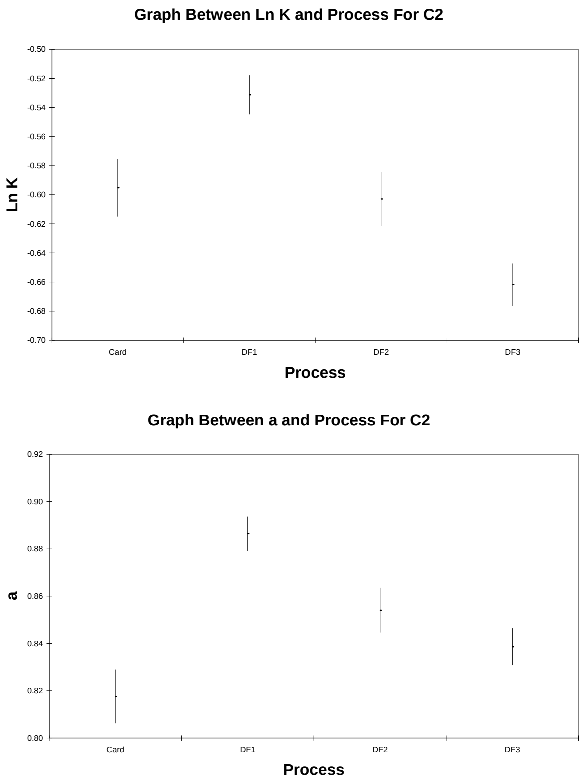


FIGURE 4. Graphical representation of Ln*k* and *a* for cotton 2.

Similar trends for Ln*k* and *a* were obtained for the remaining three types of cotton as shown in *Table III.* The authors expected the value of *a* to increase toward 1 as the fibers have been straightened and the value of *k* should remain constant. But the experimental results deviate from such considerations. These variations which were obtained by 24 tests (6 replications x 4 loads) for each type of cotton at each processing stage can only be explained by fiber crimp and hooks. First of all, let us consider how the fibers behave in the sliver during processing.

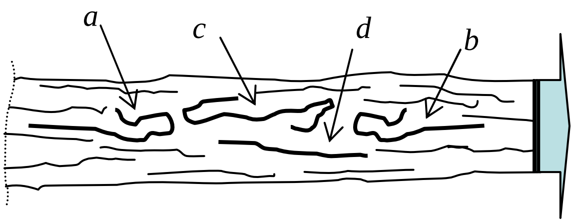


FIGURE 5. Fibers configuration in sliver.

As has been noted earlier, the fibers in the sliver have crimp and hooks. In the card sliver, more than 60% fibers present trailing hooks with respect to card delivery direction. [1] Nevertheless, there are fibers with leading hooks, fibers with both leading and trailing hooks and a small number of aligned fibers. [2] In *Figure 5*, the leading hook fibers are represented by the fiber a, the trailing hook fibers by b, both leading and trailing hooks fibers by c and the straightened fibers which represent a small number are represented by the fiber d. The fibers are also highly crimped as they leave the card.

Let us consider the fibers during drafting *Figure 6*. Each fiber, when moving in the drafting area, will be clamped initially by the feed rollers moving with the speed V_1. After crossing the drafting area, its head is clamped by the delivery rollers and will move with the speed V_2. The number of fibers n_1 entering the drafting zone are under the influence of pressure P_1 and number of fibers n_2 are under the influence of P_2. In *Figure 5*, *e* shows the ratch and e_{eff} is the effective ratch. Between the time the fiber left the incoming clamping line and the time it is taken by the outgoing cylinders, the speed of this fiber depends on the speed of the fibers in contact with it. This fiber is called the floating fiber. From *Figure 5*, it is obvious that in the drafting area there are more fibers moving with the lower speed than the higher one. This ratio decreases as the fibers approach the end of drafting area.

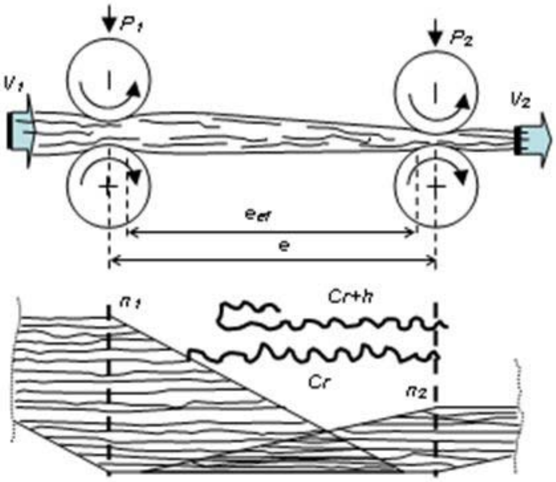


FIGURE 6. Fiber Alignement in Drafting Zone.

Now let us take the example of two fibers, one is only crimped (noted as Cr in *Figure 6*) and the other one is crimped and also presenting a hook (noted as Cr+h in *Figure 6*). During drafting, it is likely that the crimped fiber will be straightened to some extent i.e. the crimp will decrease under the effect of neighbouring fibers moving with a lower speed. The hooked fiber will be probably less decrimped than the first fiber due to the hook opening. We suppose that in this case, firstly the hook will be removed and then the fiber will be decrimped. It seems that the evaluation of hooks and crimp content is important to interpret the present results. On the other hand, the effective number of fibers in the sliver cross section is strongly affected by the hooks and the crimp. If the fibers are crimped, the number of fibers decreases with respect to sliver of the same count and composed of completely straightened fibers. Also, if the fibers are showing hooks, the effective number of fibers increases for the same sliver count. Furthermore the hooked fibers can increase the number of fibers in the sliver cross-section as the hooked end can play the role of two fibers. So, the presence of hooks and crimp affect number of fibers (N_f) in Eq. (1). Therefore this parameter should be evaluated correctly.

Let us calculate the combined affect of hooks and crimp on the values of *k* and *a* and see if there is a significant effect of these parameters on their values. The technique to calculate hooks and crimp is inspired by that of the fibrograph with some modifications. The TexLab-Peyer length measurement device is used and it seems to be more adapted for this technique. The TexLab-Peyer length measurement device consists of two parts: a fibro liner and a measuring unit. The fibro liner is used to prepare samples which are then put in the measuring unit to calculate the length. The detailed procedure is explained below::

Some slivers were juxtaposed on the bottom comb of the Fibroliner of the TexLab-Peyer device. During a machine cycle, the grip withdraws the fibers whose heads exceed the first needle row and transfers them to the upper comb in order to form a sample with aligned fiber ends. After that, this needle raw drops down out of the way and the bed of the combs moves forward. The cycle was repeated up to the required weight of fiber in the sample. During the fiber extraction, the trailing hooks (relative to the sense of the fiber extraction) are opened, but not the leading ones. The sample is then placed in the measuring unit, which gives the Hauteur distribution biased by the presence of leading hooks.

The above procedure was repeated reversing the sliver orientation in the bottom comb giving this way the Hauteur distribution biased by the presence of trailing hooks.

Finally, regardless of the sliver orientation, the prepared sample (aligned fiber ends sample) was placed again in the bottom comb, but in the reverse sense in order to open the remaining hooks, giving this way the opened-fiber length distribution (not biased by fiber hooks) designated hereafter by the adjective "aligned". The detailed description of this method will be published in near future.

The global evaluation of hook content (including the fiber crimp to a lesser extent) may be carried out by comparing the mean length of the two distributions (aligned and hooked ones) following the formula:

$$h_i(\%) = \frac{\bar{l} - \bar{e}_i}{\bar{l}} \cdot 100 \qquad (4)$$

where i index may be replaced by l (leading) or t (trailing), $\bar{l}$ and $\overline{e_i}$ are respectively the mean length of the aligned (after 3rd drawing passage) and hooked fiber distributions.

Figure 7 represents the sum of leading and trailing hooks and to some extent crimp content also.

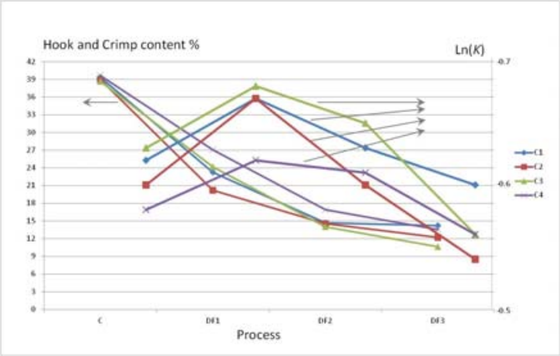


FIGURE 7. Graph of total Hook and crimp content as well as ln(K) against Process.

This graph shows at one hand that the total value of hook content and crimp is very high for the card as fibers are in entangled form. The value decreases as the fibers become more aligned after each drawing passage. On the other hand, the evolution of the inter-fiber friction does not follow the same trend as the hook and crimp content except if the card sliver is not considered. Likely, the structure of the card sliver cannot be characterized by only the global parameter of hook and crimp content. The correlation analysis *(Figure 8)* applied to the values of Lnk, a and the total values of hooks and crimp only for the drawing frame slivers emphasises that the hook content and crimp affect the frictional coefficients.

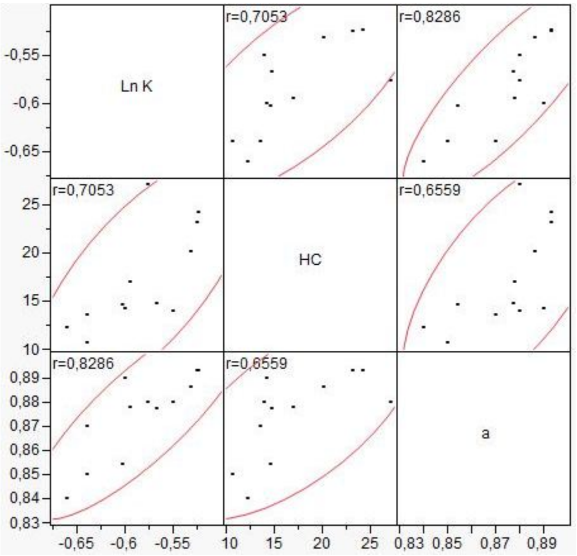


FIGURE 8. Correlation analysis between total Hook and crimp content, ln(K) and a.

At this moment, it is difficult to differentiate the effect of hooks from that of crimp. Further research is going on to solve this problem. On the other hand, the assumptions that the effective number of fibers in sliver cross-section depends upon fiber crimp and hook must be verified experimentally. Taking these assumptions into consideration, there is a strong possibility that the number of fibers calculated may deviate substantially from the actual number of fibers. This will also affect the calculation of frictional coefficients. Further calculation is under process to rectify these problems and explain the phenomena in detail.

CONCLUSION

The friction and cohesion forces are some of the most important parameters that affect the yarn spinability and tenacity. In the present work, four types of cotton card slivers were used to evaluate the inter-friction forces developed in the sliver after passing through successive drafting processes. The sliver structure in terms of hooks and crimps affect strongly the inter-fiber movement and drawing force. It is clear from the results presented here that the independent evaluation of hooks and crimp can explain the evolution of the force developed within the sliver at different processing stages.

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