THE CONTRIBUTION OF FIBER FRICTION TO YARN QUALITY

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Abstract

In this work, forty-seven upland cottons and corresponding rotor and ring spun yarns have been studied. The fiber friction parameters, fiber properties and yarn quality parameters have been measured and the data was analyzed statistically. It was found that there is an optimum level of friction between fibrous assembly at which good spinning performance and yarn quality can be achieved.

Introduction

It is well known that fiber-to-fiber friction (inter-fiber friction) is one of the major factors affecting the spinning process and determining the ultimate yarn quality. The stability and uniformity of the carded web, which would assist in the production of a uniform yarn, is due to the contribution of the frictional force between fibers. The process of drafting depends on the ease of fiber sliding over each other.

Since fiber friction is involved in the entire textile process from carding through spinning, understanding and measuring of fiber friction behavior are critically important in order to efficiently control the processing of fibrous assemblies and obtain high quality yarns [Langston *et. al*., 1954, Nanal *et. al*., 1962]. For decades, fiber friction has been studied by numerous textile workers and most of works have been centered on the development of measuring methods for fiber friction and the fundamental understanding of the nature of fiber friction [Gralen *et. al*., 1947, Howell, 1951, Broughton *et. al*., 1993, El Mogahzy *et. al*., 1993]. However, the quantitative study of the contribution of fiber friction to final yarn quality is limited and there is a lack of knowledge about at what degree the friction force should be controlled to achieve an optimum yarn quality.

The present work is to discuss measurement of inter-fiber friction of cotton fibers and to evaluate the correlation between fiber friction and cotton yarn quality parameters. Because the final yarn quality will be the combination of fiber property itself and the interaction behavior (by friction) of fibers, the correlation between fiber property parameters and cotton yarn quality is also examined together with fiber friction. Forty-seven upland cottons and the corresponding rotor and ring spun yarns have been studied. The fiber friction parameters, fiber properties and yarn quality parameters have been measured and the data as obtained is analyzed statistically.

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Experimental Procedures

Materials and Testing

For this study, a total of forty-seven upland cotton bales were included. Those cotton samples, supplied by USDA, were selected from all US growing areas, and represent leading cotton varieties from 1993 and 1994 cotton crop. The fiber friction tests and other fiber property tests used in this study are summarized in Table 1, together with symbols used for each fiber property. Among those tests, HVI and Stelometer measurement was conducted by USDA and all other measurement were accomplished in Auburn Physical Testing Laboratory.

Yarn manufacture of those cotton bales was performed on commercial textile processing equipment by USDA. The cotton was opened, blended and cleaned on Truetzchler equipment and carded on a Truetzchler Card at 70 pounds per hour. Drawing sliver was produced on a Reiter Breaker drawing Frame (3 over 3) and a Saco Lowell Finisher Drawing Frame (3 over 4). Roving was produced on a Saco Lowell Long Draft Roving Frame (10 x 5, 1-Apron Type), and ring spun yarn was produced on a Saco Lowell Long Draft Spinning Frame (2-Apron Type). Rotor spun yarn was produced on a Schlafhorst Autocoro Spinning Frame.

The measurement of yarn properties was also conducted by USDA and is summarized in Table 2, together with symbols used for each yarn property parameter. Both rotor spun yarn (Ne 10, 22, 30) and ring spun yarn (Ne 22, 36, 50) were measured, and the contribution of fiber friction to yarn quality for each spun system will be compared.

Friction Measurement

Concerning textile fibers, friction force should include two parts: (1) the conventional friction force which represents the resistance of fibers to slippage under a certain normal pressure; (2) the cohesion force which causes fibers to stick or hold together at the contact point even under zero applied load. In this work, we try to characterize those two types of friction forces. The conventional friction force will be measured using Auburn Beard Test and the cohesion force will be estimated using Rotor Ring tester.

Figure 1 shows a block diagram of our beard testing apparatus. The testing unit consists of the top clamp, two bottom clamps and the lateral pressure pistons. The top clamp is attached to a load cell with load capacity of 2.5 LBS. Two bottom clamps are mounted with an angle on a movable platen, and then clapped together to form a contact surface on both sides of the top beard. The pneumatic pistons from opposite sides of the beard allow the desired level of lateral pressure to be applied to fiber beards through two metal bars connected with the pistons. As the two bottom beards start to move down with the platen (driven by a steper-motor), friction between both sides of the top beard and the inner sides of two bottom beards is produced. The friction force is then detected by the load cell and displayed individually by a programmable digital indicator. A Labview program has been created under Windows 95 to acquire the friction force data through serial port, analyze the data and generate the friction profile, from which friction parameters can be obtained.

A typical friction profile obtained for cotton fiber is shown in Figure 2. This profile can be divided into two distinguished zones. The first zone corresponds to the friction at the denser region of the top fiber beard. Since the initial friction involves all the fibers in the beard, the friction force in the first zone is relatively higher at the beginning. As sliding continues, the decreasing of fiber numbers contacted with the fixed surface results in a gradual descend of friction force. When two bottom beards slide to the almost free end of the top beard, a marked drop of friction force due to very small numbers of fiber contact is observed in the second zone. Since two different zones represent the variation of friction force with a changing number of contacted fibers, the average forces of each zone, F_{first}, F_{second}, and the maximum force, F_{max}, are ready to be used as the friction parameters.

The detailed description of Rotor-Ring Test can be found in our published paper [El Mogahzy *et. al*., 1997]. Following the previous evaluating work on Rotor Ring, we found that the energy reading obtained from Rotor Ring varies with opening fiber length, fineness, crimp, and friction force. Normally, the fiber aggregates passing through the opening roll of Rotor Ring are unrestrained as they travel around the opening cylinder. In fact, the friction force existing in the opening process of Rotor Ring is mainly caused by entanglement, interlocking and sticking between fibers. This type of friction behavior occurs even under minimal applied load, and is referred to as fiber cohesion force. Therefore, the energy reading from Rotor Ring can be taken as a measurement of fiber cohesion force.

Results and Discussion

We have measured both 1993 and 1994 cotton crops, and the results from two years are in a good agreement. For a purpose of simplicity, we intend to present the data obtained from 1994 crop.

Table 3 gives the summary of fiber properties measured on 1994-cotton crop. It has been observed that the friction force between cotton fiber beards varies among bales, varieties and regions. It seems that cottons from San Joaquin Valley of California give a lower friction force than those from other regions. It is also found that the maximum friction force between cotton fiber beards tends to increase with increasing fiber diameter, but to be independent of fiber length. Opening energy from Rotor-Ring, representing fiber cohesion force, increases with increasing fiber length but tends to decrease with increasing fiber diameter. This result is expected, as longer and thinner fibers will give a higher cohesion force between fibers.

The relationship between yarn quality and fiber friction behaviors has been analyzed statistically for both rotor spun and ring spun yarns. The results are presented as follows.

Yarn Uniformity

As shown in Table 4, the non-uniformity of the final yarn is positively related to the maximum friction force for both rotor spun and ring spun yarns. Thus the non-uniformity of the yarn will increase as the conventional friction force increases. For ring spun yarn, increasing this friction force also results in a corresponding increase of thick and thin places in the yarn as shown in Table 5. Yarn irregularity or non-uniformity is largely introduced by the drafting process while drafting is only possible if fibers can slide over each other. Obviously, the increased friction force has an effect on limiting this sliding and restraining the formation of a uniform distribution of fibers. Therefore, the relatively lower friction between fibrous assembly will ease the textile processing and result in a good uniform spinning.

The non-uniformity, as well as thick and thin places of the yarn, has a negative correlation with energy readings, and this correlation is especially profound for rotor spun yarns as shown in Table 4 and 5. This implies that fiber cohesion force has a positive contribution to the formation of uniform yarns. At the beginning of the spinning process, the fiber web obtained from carding is a very weak and fragile network and has a low density. The stability of such an assembly will largely depend on the presence of the cohesion force. The cohesion force forms a mechanical interlocking of the crimped fibers and causes fiber to stick together at the contact points. In this way, a uniform distribution of fibers can be achieved at the carding process, which will assist in the production of a yarn having a minimum of irregularity.

Yarn Strength

As shown in Table 6, Count-Strength-Product (CSP) and yarn tenacity (T) have a negative correlation with the maximum friction force for both rotor spun and ring spun yarn, which indicates that the lower friction force will give the final yarn a higher strength. As discussed previously, decreasing the friction force between fibers will ease the textile process and assist in the production of the final uniform yarn. Indeed, improved yarn uniformity is a desirable and important characteristic in its own concerning yarn appearance. At the same time, it also delivers another important consequence, greater strength. As the strength of the given length of yarn is determined by the strength of the weakest part, it is clear that the uniformity of fiber arrangement in the yarn is more important than the existence of high local fiber strength. This may give a good explanation why there is negative correlation between friction force and the final yarn strength.

Another reason for the strength decrease with increasing the friction force is that excessive friction action between fibers will cause fiber damage during spinning process, and subsequently lead to the loss of yarn strength.

The CSP and the tenacity of the yarn have a positive correlation with energy readings from Rotor-Ring, indicating that high cohesion force will give the final yarn a higher strength. It is considered that this result is also due to a fact that the yarn uniformity increases with increasing fiber cohesion force. For the given length of yarn, the more uniform of the yarn, the higher strength it has.

As expected, the yarn strength highly depends on the fiber strength itself, and it also has a positive correlation with fiber length, but a negative correlation with fiber elongation and micronaire.

Yarn Elongation

As shown in Table 7, there is a negative correlation between the yarn elongation and energy reading, showing that the yarn elongation tends to decrease with increasing fiber cohesion force. Apparently, fiber cohesion force would resist the slippage between fibers during the yarn breakage and result in a low elongation. A weak negative correlation between the yarn elongation and the friction force can be observed from Table 7. As the friction force increases, thin places or weak points of the yarn increase and the yarn as obtained is easy to break. Thus the elongation of the yarn has a tendency to decrease.

Summary

1. The lower friction force between fibrous assembly would ease the textile process and thus produce relatively uniform and strong yarns. It appears that fiber cohesion force is more important for rotor spun yarn than for ring spun yarn in the light of forming uniform final product.

2. Increasing the fiber cohesion force and the friction force would cause the decrease of the yarn elongation.

Acknowledgment

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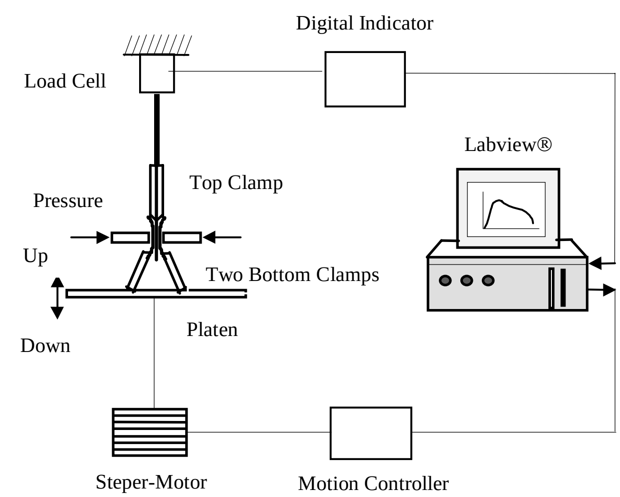

Figure 1. A schematic diagram of Auburn Beard Testing apparatus

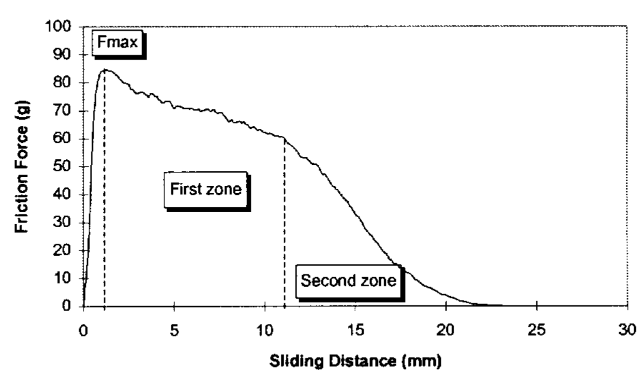

Figure 2. A typical friction profile for cotton fiber.

Table 1. The testing methods of fiber property and parameters measured

Testing Methods	Parameters measured	Symbol
Auburn Beard Test	Maximum friction force (g)	F_{max}
	Average of force in the first area under the friction profile (g)	F_{first}
	Average of force in the second area under the friction profile (g)	F_{second}
Rotor-Ring Test	Opening power readings from the first run (J)	PR_1
	Opening power readings from the second run (J)	PR_2
HVI	Opening power readings from the third run (J)	PR_3
Stelometer	Fiber length (in)	L_f
	Micronaire (rdg)	*Mic*
	1/8" – Gage Strength (g/tex)	S_f
	Elongation (%)	E_f

Table 2. Measured yarn quality parameters

Testing Methods	Parameters measured	Symbol
Yarn Skein strength Test	Count-Strength-Product (lb*Ne)	*CSP*
	Elongation (%)	E_1
Single Yarn Strength Test	Tenacity (mN/tex)	*T*
	Elongation (%)	E_2
USTER Yarn Evenness Test	Non-Uniformity (CV%)	*NU*
	Thick Places /1,000yd	*TKP*
	Thin Places /1,000yd	*TNP*

Table 3. The statistics summary of fiber properties measured on 1994 cotton crop

	Mean	Std.dev	Minimum	Maximum
F_{max} (g)	91.0	5.9	79.5	102.9
F_{first} (g)	80.4	4.4	73.7	89.8
F_{second} (g)	31.3	4.9	22.1	44.8
PR_1 (J)	15459	1308	12843	17624
PR_2 (J)	14955	1197	13324	17378
PR_3 (J)	14654	1140	12709	17169
L_f (in)	1.11	0.03	1.04	1.17
Mic	4.2	0.31	3.5	4.7
S_f (g/tex)	18.6	1.7	16.2	22.5
E_f (%)	7.6	0.8	6.5	8.9

Table 4. Correlation coefficient between yarn non-uniformity and fiber properties

	Non-Uniformity					
	Rotor Spun yarn			**Ring Spun Yarn**		
	Ne 10	Ne 22	Ne 30	Ne 22	Ne 36	Ne 50
F_{max}	0.39	0.40	0.40	0.33	0.51	0.42
F_{first}	0.29	0.25	0.32	0.24	0.39	0.29
F_{second}	-0.53	-0.43	-0.25	-0.30	-0.08	-0.34
PR_1	-0.50	-0.27	-0.43	0.19	-0.11	-0.13
PR_2	-0.55	-0.44	-0.51	-0.05	-0.28	-0.23
PR_3	-0.37	-0.33	-0.34	-0.01	-0.29	-0.13
L_f	-0.57	-0.51	-0.36	-0.30	-0.05	-0.24
Mic	0.22	0.56	0.41	0.11	0.25	0.36
S_f	-0.72	-0.67	-0.57	-0.45	-0.54	-0.68
E_f	0.34	0.08	0.25	-0.02	-0.02	0.03

Table 5. Correlation coefficient between yarn thick / thin places and fiber properties

	Thick Place					
	Rotor Spun yarn			**Ring Spun Yarn**		
	Ne 10	Ne 22	Ne 30	Ne 22	Ne 36	Ne 50
F_{max}	0.16	0.30	0.24	0.53	0.54	0.55
F_{first}	0.11	0.16	0.17	0.38	0.41	0.42
F_{second}	-0.35	-0.45	-0.15	-0.33	-0.22	-0.32
PR_1	-0.54	-0.41	-0.49	0.08	-0.03	-0.10
PR_2	-0.44	-0.51	-0.49	-0.03	-0.22	-0.22
PR_3	-0.28	-0.41	-0.42	0.11	-0.16	-0.13
L_f	-0.36	-0.55	-0.17	-0.31	-0.19	-0.30
Mic	-0.02	0.32	0.30	0.52	0.37	0.39
S_f	-0.50	-0.52	-0.44	-0.53	-0.62	-0.69
E_f	0.42	0.21	0.36	-0.21	-0.07	-0.04
	Thin Place					
	Rotor Spun yarn			**Ring Spun Yarn**		
	Ne 10	Ne 22	Ne 30	Ne 22	Ne 36	Ne 50
F_{max}	-0.01	0.31	0.35	0.49	0.58	0.50
F_{first}	-0.08	0.22	0.34	0.33	0.44	0.36
F_{second}	-0.22	-0.35	-0.05	-0.46	-0.25	-0.38
PR_1	-0.22	-0.29	-0.47	0.06	-0.06	-0.17
PR_2	-0.36	-0.35	-0.58	-0.07	-0.24	-0.27
PR_3	-0.37	-0.19	-0.45	0.10	-0.14	-0.16
L_f	-0.19	-0.41	-0.24	-0.46	-0.29	-0.34
Mic	-0.27	0.38	0.25	0.54	0.38	0.32
S_f	-0.13	-0.58	-0.54	-0.50	-0.63	-0.68
E_f	0.49	0.31	0.42	-0.21	-0.08	-0.01

Table 6. Correlation coefficient between yarn strength and fiber properties

	CSP					
	Rotor Spun Yarn			**Ring Spun Yarn**		
	Ne 10	Ne 22	Ne 30	Ne 22	Ne 36	Ne 50
F_{max}	-0.43	-0.53	-0.51	-0.56	-0.54	-0.55
F_{first}	-0.35	-0.46	-0.44	-0.48	-0.45	-0.46
F_{second}	0.25	0.33	0.34	0.38	0.41	0.43
PR_1	0.24	0.44	0.44	0.45	0.39	0.39
PR_2	0.43	0.62	0.65	0.60	0.59	0.57
PR_3	0.38	0.48	0.50	0.46	0.44	0.42
L_f	0.31	0.45	0.47	0.50	0.54	0.54
Mic	-0.21	-0.15	-0.17	-0.15	-0.20	-0.19
S_f	0.77	0.91	0.91	0.92	0.90	0.89
E_f	-0.36	-0.46	-0.45	-0.43	-0.38	-0.36
	Tenacity					
	Rotor Spun Yarn			**Ring Spun Yarn**		
	Ne 10	Ne 22	Ne 30	Ne 22	Ne 36	Ne 50
F_{max}	-0.56	-0.50	-0.48	-0.53	-0.52	-0.74
F_{first}	-0.51	-0.41	-0.41	-0.45	-0.45	-0.64
F_{second}	0.22	0.31	0.40	0.38	0.35	0.31
PR_1	0.36	0.33	0.42	0.41	0.33	0.26
PR_2	0.57	0.54	0.63	0.63	0.53	0.47
PR_3	0.44	0.42	0.50	0.48	0.39	0.35
L_f	0.34	0.36	0.46	0.54	0.47	0.58
Mic	-0.15	-0.23	-0.29	-0.24	-0.25	-0.22
S_f	0.92	0.80	0.86	0.93	0.89	0.73
E_f	-0.48	-0.33	-0.33	-0.44	-0.40	-0.11

Table 7. Correlation coefficient between yarn elongation and fiber properties

	Elongation from Skein Yarn Test					
	Rotor Spun yarn			Ring Spun Yarn		
	Ne 10	Ne 22	Ne 30	Ne 22	Ne 36	Ne 50
F_{max}	-0.22	-0.26	-0.13	-0.18	-0.10	-0.33
F_{first}	-0.06	-0.11	-0.3	-0.04	0.07	-0.16
F_{second}	0.30	0.14	0.17	-0.03	0.18	0.18
PR_1	-0.35	-0.48	-0.55	-0.58	-0.59	-0.58
PR_2	-0.36	-0.51	-0.45	-0.65	-0.50	-0.52
PR_3	-0.33	-0.53	-0.40	-0.63	-0.57	-0.58
L_f	0.10	-0.01	0.00	-0.22	-0.01	0.05
Mic	-0.46	-0.52	-0.56	-0.47	-0.61	-0.51
S_f	0.00	-0.13	-0.29	-0.44	-0.38	-0.14
E_f	0.56	0.73	0.80	0.78	0.83	0.70

	Elongation from Single Yarn Test					
	Rotor Spun yarn			Ring Spun Yarn		
	Ne 10	Ne 22	Ne 30	Ne 22	Ne 36	Ne 50
F_{max}	0.03	-0.05	-0.06	-0.09	-0.24	-0.17
F_{first}	0.14	0.07	0.04	0.02	-0.11	-0.05
F_{second}	0.14	0.11	0.10	0.00	0.02	0.12
PR_1	-0.53	-0.58	-0.48	-0.68	-0.65	-0.59
PR_2	-0.44	-0.44	-0.37	-0.54	-0.53	-0.56
PR_3	-0.46	-0.47	-0.40	-0.56	-0.54	-0.59
L_f	-0.05	-0.08	-0.08	-0.13	-0.03	-0.03
Mic	-0.51	-0.60	-0.57	-0.58	-0.69	-0.57
S_f	-0.46	-0.43	-0.38	-0.50	-0.27	-0.32
E_f	0.87	0.86	0.80	0.87	0.76	0.83