Study on Pile Fabrics

Part 4: Investigation of Factors Affecting Frictional Properties of Pile Fabrics

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Abstract

This study aims at investigating experimentally frictional properties of pile fabrics by changing such factors as sliding speeds of a frictional slider, relative humidity, twist numbers of a pile warp yarns and frictional directions. The results are as follows.

(1) The frictional force is influenced by the sliding speed of a frictional slider.

(2) As it is found that the frictional force is influenced by relative humidity, such assumption is made as

$$F(H) = f_{AY} \cdot A(H) + b \cdot W(H)$$

where f_{AY} and b are constants, H being relative humidity.

There was found a good agreement between experimental values and calculated values.

(3) The frictional force increases as the twist number of pile warp yarns decreases.

(4) The frictional coefficient (μ_a) obtained by sliding against inclined piles is higher than that (μ_w) obtained by sliding along inclined piles.

1. Introduction

In the previous paper^[1], the frictional force between pile yarns and a frictional slider was measured in order to study the frictional mechanism of pile fabrics, and it was found the frictional force could be expressed by the experimental equations $F = f_{AY} \cdot A + b \cdot W$ and $F = K_1 \cdot R^m + K_2 \cdot R^n$, and that there was a good agreement between experimental values and calculated values.

There are many studies^[2-30] on the factors affecting the frictional properties of fibers (such as pressure^[4-6], relative humidity, frictional speed^[5,7], temperature^[5,7-9], lubricant^[10-23], and frictional direction^[24-28]), and on the factors^[29,30] affecting the frictional properties of yarns such as (fiber length, yarn count, twist number, frictional speed, relative humidity and lubricant).

As there are no papers on factors affecting the frictional properties of pile fabrics, frictional properties were studied by changing frictional speed, relative humidity, twist numbers of pile warp yarns and frictional direction.

2. Experimental

Samples selected to study the relation between frictional force and sliding speed are T_1 , T_2 and T_3 shown in Table 1.

Table 1 Samples used

	Sample		
	T_1	T_2	T_3
Yarn count (s)			
Ground warp	30/2	42.6/2	17.8
Weft	20	31.6	23.1
Pile warp	20	41.2/2	31.8/2
Fabric density			
Warp density (end/inch)	38	46	32
Weft density (end/inch)	38	58	52
Pile ratio	4.9	5.0	5.2

Frictional forces at various frictional speeds were measured under the conditions shown in Table 2(A), using a frictional measuring apparatus.

Samples selected to study the relation between frictional force and relative humidity are T_1 and T_3 . The frictional forces at various relative humidity were measured under the conditions shown in Table 2(B).

Samples to study the relation between frictional force and twist numbers are T_4 , T_5 , T_6 , T_7 , T_8 and T_9 shown in

Table 2 Measuring conditions

	(A)	(B)	(C)
Sliding speed (mm/s)	0.5, 5, 15, 60, 120	5	5
Pressure (gf/cm ²)	2.125	0.48, 0.855, 1.48, 2.125, 2.75, 3.375, 4.625	2.125
Sliding length (mm)	100	100	100
Temperature (°C)	20	20	20
Humidity (% RH)	65	55, 65, 80, 90	65

Table 3 Samples used

	Sample					
	<i>T</i> ₄	<i>T</i> ₅	<i>T</i> ₆	<i>T</i> ₇	<i>T</i> ₈	<i>T</i> ₉
Yarn count (s)						
Ground warp	40.0/2	40.0/2	40.0/2	30.0	30.0	30.0
Weft	20.0	20.0	20.0	20.0	20.0	20.0
Pile warp	40.0/2	40.0/2	40.0/2	20.0	20.0	20.0
Twist numbers of pile warp yarns (t/cm)	3.5	6.3	7.8	3.0	6.7	7.8
Fabric density						
Warp density (end/inch)	46	46	46	50	50	50
Weft density (end/inch)	56	56	56	52	52	52
Pile ratio	4.1	4.1	4.1	5.1	5.1	5.1

Table 4 Samples used

	Sample							
	<i>T</i> ₁₀	<i>T</i> ₁₁	<i>T</i> ₁₂	<i>T</i> ₁₃	<i>T</i> ₁₄	<i>T</i> ₁₅	<i>T</i> ₁₆	<i>T</i> ₁₇
Yarn count (s)								
Ground warp	39.4/2	39.2/2	44.2/2	42.6/2	17.8	31.8/2	20.0	20.0
Weft	22.1	21.6	16.9	31.6	23.1	18.3	20.0	20.0
Pile warp	29.8/2	32.8/2	20.9	41.2/2	31.8/2	31.4/2	34.0/2	34.0/2
Fabric density								
Warp density (end/inch)	40	37	38	46	34	32	30	30
Weft density (end/inch)	53	51	45	58	51	52	44	44
Pile ratio	4.80	5.19	6.90	5.00	7.40	5.20	4.00	7.40
	Sample							
	<i>T</i> ₁₈	<i>T</i> ₁₉	<i>T</i> ₂₀	<i>T</i> ₂₁	<i>T</i> ₂₂	<i>T</i> ₂₃	<i>T</i> ₂₄	
Yarn count (s)								
Ground warp	20.8	20.0/2	30.0/2	20.0/2	30.0/2	30.0/2	16.0	
Weft	20.2	20.0	20.0	20.0	15.0	23.0	16.0	
Pile warp	17.3	16.0	23.0	20.0	20.0/2	30.0/2	30.0/2	
Fabric density								
Warp density (end/inch)	60	34	32	34	30	38	34	
Weft density (end/inch)	48	57	51	64	68	62	50	
Pile ratio	6.70	2.10	2.01	2.13	1.00	1.00	1.00	

Table 3. The twist numbers of pile warp yarns for each sample were different, Frictional force was measured under the conditions shown in Table 2(C).

Samples to study the relation between frictional force and

frictional direction are *T*₁₀–*T*₁₈ shown in Table 4. The frictional coefficients along inclined piles (μ_w) and those against inclined piles (μ_a) were measured with a KES surface testing machine.

3. Result and Discussion

3.1 Effect of Sliding Speed of Frictional Slider

Figure 1 shows the relation between frictional forces and sliding speeds. Figure 2 shows the relation between frictional forces and sliding lengths at various sliding speeds.

●; Sample T_1 , ▲; Sample T_2 , ■; Sample T_3

Fig. 1 Relation between frictional force and sliding speed of a frictional slider

The frictional force decreases with increasing the sliding speed at low speed (0.5–5 mm/s) as shown in Fig. 1. Figures 2 (a) and (b) show the stick-slip motion. As the frictional speed increases higher, this motion changes into smooth sliding and the frictional force becomes constant.

At high speed, the frictional force increases gradually.

It is found that the frictional force is influenced by the sliding speed.

3.2 Effect of Relative Humidity

It is important to confirm whether the relative humidity of pile fabrics reaches equilibrium at given relative humidity.

At high relative humidity (90% RH), the time until the relative humidity of pile fabrics reaches equilibrium is about two hours as shown in Fig. 3. So samples were left at each relative humidity for three hours in the laboratory.

Figure 4 shows the relation between frictional forces and pressures at each relative humidity.

As shown there, the frictional force increases with increasing relative humidity.

Table 5 show the changes of fiber and yarn diameter.

As fibers and yarns absorb moisture when the relative humidity increase, their diameters, become bigger and the

Sliding speed;

(a) 0.5 mm/s, (b) 5, (c) 15, (d) 30, (e) 60, and (f) 120 mm/s.

Fig. 2 Relation between frictional force and sliding length at various sliding speed (Sample T_1).

●; Sample T_1 , ○; Sample T_3

Fig. 3 Changes of relative humidity of samples T_1 and T_3

Fig. 4 Relation between frictional force and pressure at various relative humidity

real contact area between a yarn and a frictional slider increases.

Table 5 Changes of fiber and yarn diameters

Diameter (mm)		
Fiber	65 %RH	90 %RH
American cotton	0.027	0.030
Egyptian cotton	0.020	0.022
Indian cotton	0.031	0.034
Diameter (mm)		
Yarn	65 %RH	90 %RH
12s cotton yarn	0.249	0.300
15s cotton yarn	0.251	0.275
20s cotton yarn	0.215	0.240

In the previous paper^[1], the relation among frictional force (F), real contact area (A) and loss energy (W) is expressed by

$$F = f_{AY} \cdot A + b \cdot W \quad \dots\dots\dots (1)$$

where f_{AY} and b are constants.

Table 6 shows real contact area and loss energy at each pressure. As shown there, A and W increase with increasing relative humidity. Table 7 shows the comparison between experimental values and calculated values by eq. (1) at each relative humidity, in which f_{AY} of sample T_1 is 56.12 at 55% RH, 48.82 at 65% RH and 53.01 at 90% RH, and that of sample T_3 is 45.51 at 55% RH, 42.60 at 65% RH and 44.98 at 90% RH. As shown in Table 7, there is a good agreement between experimental and calculated values.

Table 6 Real contact area (A) and loss energy (W) at each pressure
(a) Sample T_1

Pressure (gf/cm²)	55% RH		65% RH		90% RH	
	A (cm²)	W (gf·cm/cm²)	A (cm²)	W (gf·cm/cm²)	A (cm²)	W (gf·cm/cm²)
0.480	0.04	0.1127	0.05	0.1430	0.09	0.2484
0.855	0.06	0.1863	0.07	0.2364	0.10	0.4106
1.480	0.09	0.3007	0.11	0.3814	0.16	0.6624
2.125	0.12	0.4121	0.14	0.5227	0.20	0.9078
2.750	0.15	0.5159	0.17	0.6544	0.24	1.1366
3.375	0.17	0.6167	0.20	0.7822	0.29	1.3585
4.625	0.21	0.8116	0.25	1.0294	0.36	1.7879

(b) Sample T_3

Pressure (gf/cm²)	55% RH		65% RH		90% RH	
	A (cm²)	W (gf·cm/cm²)	A (cm²)	W (gf·cm/cm²)	A (cm²)	W (gf·cm/cm²)
0.480	0.05	0.0722	0.06	0.0916	0.10	0.1557
0.855	0.08	0.1440	0.10	0.1827	0.13	0.3106
1.480	0.13	0.2776	0.15	0.3521	0.17	0.6201
2.125	0.16	0.4278	0.19	0.5426	0.20	0.9391
2.750	0.19	0.5822	0.23	0.7385	0.24	1.2628
3.375	0.22	0.7437	0.26	0.9433	0.28	1.6130
4.625	0.28	1.0839	0.33	1.3748	0.35	2.3509

Table 7 Comparison between measured values and calculated values by eq. (1) at each relative humidity

(a) Sample T_1

Pressure (gf/cm ²)	$F(\text{gf})$					
	55% RH		65% RH		90% RH	
	cal.	meas.	cal.	meas.	cal.	meas.
0.480	2.470	2.470	2.727	2.727	5.268	5.268
0.855	3.740	3.588	3.700	3.889	6.122	7.85
1.480	5.652	6.015	6.133	6.566	9.806	10.2982
2.125	7.559	7.734	7.880	8.216	12.418	12.799
2.750	9.450	9.597	9.608	9.679	14.996	14.632
3.375	10.774	10.793	11.328	10.940	18.090	16.346
4.625	13.408	14.764	14.264	15.816	22.659	21.734

(b) Sample T_3

Pressure (gf/cm ²)	$F(\text{gf})$					
	55% RH		65% RH		90% RH	
	cal.	meas.	cal.	meas.	cal.	meas.
0.480	2.420	2.420	2.739	2.739	4.809	4.809
0.855	3.929	3.668	4.625	4.230	6.469	6.405
1.480	6.472	5.852	7.094	6.251	8.851	8.301
2.125	8.137	7.951	9.179	8.821	10.874	9.803
2.750	9.811	9.291	10.568	9.496	13.321	12.525
3.375	11.500	11.310	12.963	12.597	15.870	14.435
4.625	14.911	14.724	16.808	15.879	20.445	19.787

Fig. 5 Comparison between experimental values and calculated values from eq. (2)

As it is expected that the F dependency on relative humidity is related with the A and W dependency on relative humidity, eq. (1) becomes:

$$F(H) = f_{AV} \cdot A(H) + b \cdot W(H) \quad \dots\dots\dots (2)$$

where H is relative humidity.

Figure 5 shows the comparison between experimental values (points) and calculated values from eq. (2) (curved lines) at each pressure. It shows a good agreement between experimental and calculated values.

3.3 Effect of Twist Number

The frictional force between a yarn bundle and a frictional slider was measured with a frictional measuring apparatus at 20°C and 65% RH by setting the sliding speed at 5.0 mm/s and a sliding length at 150 mm. Numbers of yarn bundles used are 2, 5, and 10, and the yarn count is 15 s, twist numbers 4.23, 5.5 and 6.3 tpc.

Figure 6 shows the relation between frictional force and load per one yarn. As shown there, the frictional force decreases when the twist number increases, and the difference between each sample becomes bigger when the yarn number contacting with the frictional slider and load increase.

Frictional forces of pile fabrics were measured and shown in Table 8. As shown there, frictional forces in warp and weft directions decrease when twist numbers of pile warp yarns increase. As fibers of pile warps are restricted by

Yarn twist is 4.3 (●), 5.5 (△), and 6.3 (■) tpc.
 Fig. 6 Relation between frictional force and load. The yarn numbers contacting with the frictional slider are 2 (Fig. a), 5 (Fig. b), and 10 (Fig. c)

twist torque when the twist number increases, the yarn width becomes smaller. Therefore, the real contact area between pile warps and a frictional slider becomes smaller, and the frictional force decreases when the twist number of a pile warp increases.

Table 8 Frictional forces of samples T_4 – T_9

Sample	Frictional force (gf)	
	Warp direction	Weft direction
T_4	7.50	7.75
T_5	6.27	6.10
T_6	6.18	6.01
T_7	7.22	6.32
T_8	6.25	6.13
T_9	6.10	6.02

3.4 Effect of Frictional Direction

Table 9 shows frictional coefficients along the scale direction (μ_w) and against the scale direction (μ_a). As shown there, it is found that μ_a is generally larger than μ_w .

Table 9 Frictional coefficients μ_w and μ_a of samples T_{10} – T_{18}

Sample	Frictional coefficient	
	μ_w along the scale	μ_a against the scale
T_{10}	0.5360	0.5960
T_{11}	0.5750	0.6420
T_{12}	0.5152	0.5529
T_{13}	0.5230	0.5469
T_{14}	0.6230	0.7293
T_{15}	0.4201	0.5675
T_{16}	0.4423	0.9940
T_{17}	0.5257	0.5522
T_{18}	0.5381	0.6068

Table 10 Frictional coefficients μ_w and μ_a of samples T_{19} – T_{24}

Sample	Frictional coefficient	
	μ_w	μ_a
T_{19}	0.5751	0.5770
T_{20}	0.4695	0.4619
T_{21}	0.5610	0.5539
T_{22}	0.3921	0.3865
T_{23}	0.2964	0.2981
T_{24}	0.3120	0.3069

Table 10 shows measured μ_w and μ_a of samples T_{19} , T_{20} and T_{21} whose pile inclination angles are approximately 90° .

Their details are shown in Table 4. As shown there, there are no difference between μ_w and μ_a , because there is no difference of the frictional direction as piles stand perpendicularly. Table 10 also shows frictional coefficients of backing fabrics T_{22} , T_{23} and T_{24} as shown in Table 4. As shown there, μ_w and μ_a values of backing fabrics are smaller than those of pile fabrics, and there is no difference between μ_w and μ_a . This is because that the real contact area with the frictional slider becomes smaller as there is no pile on backing fabrics.

Therefore the frictional coefficient is influenced by the frictional direction, and μ_a is larger than μ_w .

4. Conclusion

The frictional properties of pile fabrics were studied by changing sliding speed, relative humidity, twist number and frictional direction.

The results obtained are as follows.

(1) As the frictional force is influenced by the relative humidity, the following experimental equation is made:

$$F(H) = f_{AV} \cdot A(H) + b \cdot W(H)$$

There was a good agreement between experimental and calculated values.

(2) The frictional force increases when the twist number of pile warps decreases.

(3) The frictional coefficient is influenced by the frictional direction, and μ_a is larger than μ_w .

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