DESIGN OF A NEW INSTRUMENT FOR MEASURING FRICTIONAL PROPERTIES OF WOVEN FABRICS

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Abstract Friction measurement is one of the important and interesting problems in the study of handle properties of fabrics. Different methods have been developed for measuring friction, such as sliding, Kawabata Evaluation System (KES) and cyclic testing. In this research, considering the possibilities of varying conditions in measuring friction, a new instrument is used in which the bottom surface of fabric can be moved and the top slider is kept fixed in order to prevent slider vibrations. In this method, the force inserted by an extensible yarn connected to the trolley standing on four very smooth bearings was measured. The result of experiments confirmed 7.6% increase in correlation coefficient in the dynamic friction region for nine different test samples and about 4.6% reduction in coefficient of variation compared to the sliding type.

Keywords: Frictional properties, Woven fabrics, Dynamic friction, Static friction

چکیده اندازه گیری اصطکاک یکی از مسائل مهم و مورد توجه در مطالعه خواص زیر دست پارچه است. روشهای متعددی برای اندازه گیری اصطکاک نظیر سیستم اندازه گیری کاواباتا (KES) و روش آزمایش سیکلی وجود دارد. در تحقیق حاضر روش جدید اندازه گیری اصطکاک، با بکار گیری سطح زیرین متحرک پارچه و ثابت نگه داشتن بخش وارد کننده اصطکاک امکان سنجی شده است. در روش ارائه شده برای ایجاد نیروی حرکتی از نخ غیر قابل کشیدگی استفاده شده است که موجب حرکت واگنی با چهار بلبرینگ بدون اصطکاک می گردد. نتایج نشان میدهد مقدار ضریب تعیین در ناحیه اصطکاک دینامیکی برای ۹ نمونه به مقدار ۷/۶% نسبت به روش لغزشی افزایش یافته است و ضریب تغییرات در مقایسه با روش لغزشی به مقدار ۴/۶% کاهش یافته است.

1. INTRODUCTION

The neurological mechanism of human sensing is very complicated, especially for evaluation of fabric properties. Visual observations on surface of fabric can be sensitive to some properties and after touch with hand can be achieved other than very important subjective properties. Surface friction is one of the important properties that can be sensed with hands and can be discriminated more accurately compared with other instrumental measured frictional properties. Many researchers have pointed out technological problems as other reasons for measuring frictional properties. Information on the knowledge of frictional characteristics is required in industry for measuring friction in textile materials which justifies the need for more research for developing new ideas in this field.

In 1969 Amontons proposed a simple linear law of friction, $F = \mu . N$, where F is the frictional force, μ is the coefficient of friction, and N is the force acting normal to the surface. However, textile materials have been known to deviate from this law of friction [1, 2, 3, 4 and 14]. Experimental research has shown that the frictional force with normal load relationship has not a simple linear relationship as above [5, 6]. According to Bowden and Tabor theory, junctions are formed at the points of real area contact and the frictional force is given by the product of true area of contact and bulk specific shear strength of the junctions.

In more detail, frictional behavior properties of viscoelastic materials such as fabrics can be explained by a power law of friction given as $F = CN^n$, where F is the frictional force, N is the normal force and C is a contact coefficient (equal to μ only when n=1) and n is the frictional index[7]. For determination of the parameters C and n, many researchers have used tensile strength testers with some attachments to measure fabric to fabric or fabric to metal frictional properties as shown in Fig. 1 [8].

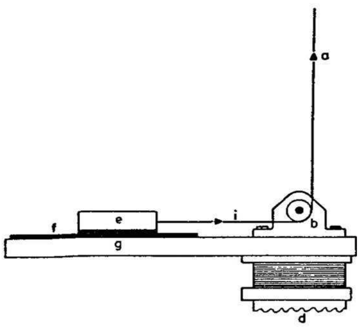

Figure 1. Schematic of a friction tester [8]

In all of the reported research, static and kinetic frictional resistance was determined directly from the frictional trace [9]. The highest peak in the start of motion was taken as the static frictional resistance (F_s). The mean of peaks and troughs was taken as the kinetic frictional resistance (F_k) [10].

Other test methods for measuring frictional properties have also been reported. Drebby [11] found that when a fabric was repeatedly dragged on another fabric, a reduction in the frictional force occurred. He used 10 cycles to bring frictional force in stable level. Zurek, et. al. [12] have modified Drebby method and used a holding carriage for cycle testing. Fig. 2 shows the variation of frictional force in reciprocating motion of the carriage.

Apurba, et. al. [13] developed a new instrument consisting of three measuring devices namely a load cell, a linear variable differential transformer (LVDT) and an encoder. Data obtained in this instrument can assess the frictional variation of the surface of fabric very sensitively, but this instrument was not used as a tensile strength tester in general textile laboratories because it needed special care for adjustment and maintenance.

In all previous experiments an appropriate control in the trace of sliding could not be observed, therefore, error in predicting frictional constant is higher than the actual surface friction. In a mathematical study [14], it is specified that frictional characteristics have a linear logarithmic relationship with normal load and coefficient of friction, i.e.:

$$\log(F_i/A) = \log(C) + n\log(N_i/A) \quad i=1,2,\ldots,m \quad (1)$$

where:

F_i: friction force in Newton
A: apparent area in m^2
C: friction parameters in $Pascal^{1-n}$
n: friction index (non –dimensional)
N_i: normal loads in Newton
m: number of experimental observations
This can be expressed in matrix form as:

$$\begin{pmatrix} Y_1 \\ Y_2 \\ \vdots \\ Y_m \end{pmatrix} = \begin{pmatrix} 1 & \log(N_1/A) \\ 1 & \log(N_2/A) \\ \vdots & \vdots \\ 1 & \log(N_m/A) \end{pmatrix} \begin{pmatrix} logC \\ n \end{pmatrix} \rightarrow \vec{Y} = B\vec{\alpha} \quad (2)$$

where:

$Y_i = \log(F_i/A)$ *and* $\vec{Y}$ *is* $[Y_1, Y_2, \ldots, Y_m]'$

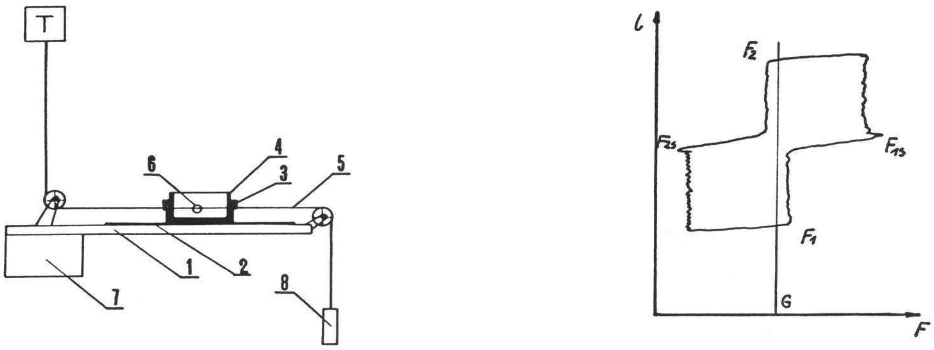

Figure 2. Diagram of the device and variation of the frictional force during reciprocating motion [12]

Nonlinear error can be calculated with regression analysis:

$$e_L = \sum_{i=1}^{m}\left(\log\left(\frac{F_i}{A}\right) - \log(C) - nlog\left(\frac{N_i}{A}\right)\right)^2 \quad (3)$$

This term expresses the collective dispersion in friction force in the neighborhood of regression line. When the error is large, the relationship between log (N/A) and log (F/A) is no longer linear and the regression line cannot explain these deviations. However, dividing the explained variation by total variation provides a simple method of calculating sample coefficient of determination, i.e.:

$$r^2 = \frac{Explained\ variation}{total\ variation} = 1 - \frac{S_{Y.X}^2}{S_Y^2}\left(\frac{n-2}{n-1}\right) \quad (4)$$

where, $S_{Y.X}^2$ = standard error of the estimate
S_Y^2 = standard deviation
n=number of observations.

Obviously, the closer r^2 is to one in value, the greater is the degree of correlation, and so the data will be less scattered around the fit line. In this study the value for coefficient of determination is calculated for the first time. Results of general previous tests indicate that the coefficient of determination is very scattered and is actually much less than one.

Design of the Instrument In this new instrument, the sample surface is moved in a different fashion from the previous methods and the sliding object is kept fixed on the surface as shown in Figure 3. The instrument is designed such that one side is connected to the lower jaw of the strength tester and the other side is fixed to a suitably designed escalator. On this surface a suitable rail is attached in order to control the movement of the trolley. The newly designed trolley has four bearings for making movements as frictionless as possible. By using a rectangular holder fixed to the slider surface, the upper fabric is not allowed to move and is kept fixed. The trolley is connected to the upper jaw of the strength tester with an extensible yarn. Now, when the upper jaw is moved, the force can be measured by a load cell connected to the upper jaw.

2. EXPERIMENTAL METHOD

In the new method of measuring friction we have used:

1. Fabric sample with dimensions 15×20 cm fixed on the trolley plate with a suitable pretension. The direction of sample can be either in warp or weft, but are close to the warp.
2. Slider dimension was designed to be 8×5 cm. and the fabric was fixed on it with a suitable tension in the range 20 to 100 g/cm^2.
3. An inextensible thread was connected to the platform plate which stood on four frictionless bearings and the other end was clamped to upper jaw of the tensile strength tester.
4. A sledge stood on the upper surface of fabric and was fixed on the back of holder. A dead weight was inserted over the sledge. In this study, these dead weights of 250, 300 and 350 grams were used.

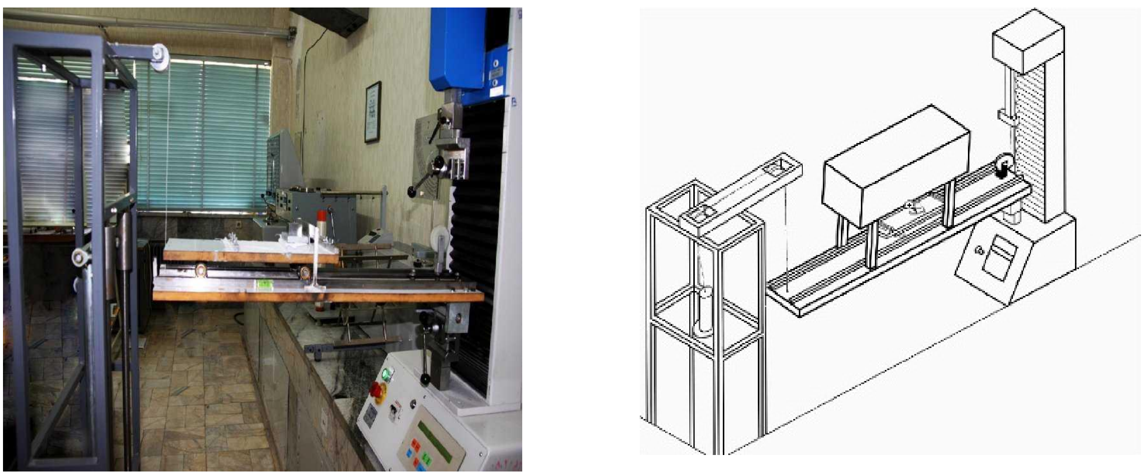

Figure 3. Diagram of the new device for measuring the frictional force with designed escalator

5. A strength tester with constant speed of 5 cm/min pulled up the plate of friction tester and the results of the test were recorded by computer software, (strength tensile software).
6. In the force–elongation curve obtained with tensile strength tester, the value of the first highest peak shows the value of static friction and mean of sequence force shows the dynamic force (see Fig. 3).
7. Steps 1 to 6 were repeated for other samples as many times as necessary.

3. RESULTS AND DISCUSSION

As mentioned before, in this research the effect of friction was investigated in a new manner and was compared with previous results. The experimental results are presented in Table 1. In this table the parameters n and C are computed for a 9 different fabric samples. To be able to compare the results with the previous method, the same samples were tested and following table shows the properties of samples used for tests.

F_s and F_k can be obtained in a similar method as in the previous research [7]. By using

$$\log(F_i/A) = \log(C) + n\log(N_i/A)$$

n and C as μ_s and μ_k can be obtained, respectively. The test results for nine fabrics are shown in Table 2.

For comparing the results of the new test method with the previous friction tester, conventional tests were performed with the new friction tester. First, the trolley was fixed and then the inextensible

TABLE 1. Details of fabric samples under test experiment

Fabric code	Yarn count		Fabric structure	Threads/cm		Yarn count (tex)		Yarn crimp (%)		Cover factor		Mass (gr/m^2)	Thickness(mm)
	Warp	Weft		Warp	Weft	Warp	Weft	Warp	Weft	Warp	Weft		
1	p/v	P	Plain	28	23	39.4	16.7	4.54	7.14	0.66	0.35	177	0.49
2	P	P	Crepe	40	22	16.7	16.7	2.3	4.94	0.61	0.34	130	0.34
3	P	p/v	Plain	33	26	16.7	19.7	10.46	3.67	0.51	0.43	120	0.38
4	p/w	p/w	Twill	32	24	39.4	39.4	6.88	6.18	0.75	0.57	230	0.55
5	P	p/w	Twill	33	24	30	29.5	6.06	12.5	0.23	0.49	182	0.86
6	V	V	Plain	26	23	19.7	19.7	5.81	16.16	0.43	0.38	128	0.51
7	C	C	Twill	43	23	19.7	29.5	16.35	12.61	0.72	0.47	288	0.85
8	p	p	Plain	45	36	34.5	16.7	2.69	1.85	0.49	0.55	130	0.18
9	p/c	p/c	Plain	47	30	14.8	14.8	11.11	6.86	0.68	0.43	210	0.34

p/v : polyester/viscose, p: polyester, p/w: polyester/wool , p/c: polyester/cotton

TABLE 2. Frictional parameters of fabrics with new test method

sample	static						kinetic					
	C			n			C			n		
	$\bar{X}$	S	CV%	$\bar{X}$	S	CV%	$\bar{X}$	S	CV%	$\bar{X}$	S	CV%
1	0.524	0.0208	3.97	0.8354	0.0706	8.45	0.856	0.0484	5.66	0.7197	0.0108	1.498
2	0.6947	0.0530	7.62	0.6927	0.0.073	10.54	1.1210	0.0145	1.29	0.4403	0.0127	2.88
3	0.6427	0.0431	6.70	0.8313	0.0342	4.11	0.8953	0.0495	5.53	0.7957	0.0935	11.74
4	0.6660	0.0639	9.59	0.8077	0.0356	4.41	0.9401	0.0843	8.963	0.608	0.098	16.12
5	0.3523	0.0491	13.94	1.1737	0.043	3.66	0.690	0.095	13.76	1.2337	0.1201	9.74
6	0.5583	0.0318	5.7	0.7387	0.024	3.25	1.04	0.02	1.923	0.454	0.0239	5.2633
7	0.27	0.0371	13.74	1.070	0.0623	5.82	0.7353	0.0452	6.14	1.015	0.1174	11.56
8	0.3954	0.021	5.311	1.112	0.054	4.856	0.3324	0.0352	10.58	1.2118	0.035	2.88
9	0.6433	0.0439	6.82	0.7287	0.0571	7.84	1.03	0.03	2.91	0.558	0.033	5.92

TABLE 3. Frictional parameters of fabrics with conventional test method

sample	Static						kinetic					
	C			N			C			n		
	$\bar{X}$	S	CV%	$\bar{X}$	S	CV%	$\bar{X}$	S	CV%	$\bar{X}$	S	CV%
1	0.4737	0.1206	25.45	1.0317	0.0587	5.68	0.5367	0.0717	13.36	1.063	0.058	5.45
2	0.4223	0.0673	15.9	1.0493	0.0503	4.79	0.4350	0.0720	16.55	1.074	0.0459	4.27
3	0.5523	0.1175	21.27	0.9507	0.1075	11.3	0.5363	0.1217	22.69	0.9893	0.0992	10.02
4	0.7297	0.1232	16.87	0.7837	0.022	2.81	0.8453	0.1045	12.36	0.800	0.0456	5.7
5	0.7060	0.05	7.15	0.5287	0.0925	17.49	0.8167	0.1306	16.0	0.5943	0.039	6.56
6	0.9320	0.2215	23.76	0.4953	0.0846	17.08	0.7577	0.0655	8.64	0.6473	0.0255	3.93
7	0.8107	0.0768	9.47	0.4287	0.0633	14.76	0.977	0.084	8.599	0.3693	0.0699	18.93
8	0.4193	0.018	4.29	1.2213	0.0726	5.944	0.3713	0.0398	10.71	1.232	0.0451	3.66
9	0.7343	0.077	10.48	0.8303	0.1212	14.59	0.6765	0.0672	9.941	0.956	0.098	10.25

TABLE 4. Regression analysis

sample	Weight						
	R of weight 1 (250 gr)		R of weight2 (300 gr)		R of weight3 (350 gr)		Mean difference of correlation coefficient
	New	conventional	New	conventional	New	conventional	$mean\ of\ (r_{new} - r_{con})\%$
1	0.851	0.641	0.82	0.84	0.779	0.619	11.67
2	0.81	0.757	0.533	0.415	0.424	0.455	4.67
3	0.808	0.601	0.645	0.553	0.704	0.836	5.567
4	0.88	0.72	0.817	0.53	0.786	0.7	17.767
5	0.802	0.527	0.869	0.753	0.856	0.801	14.867
6	0.802	0.696	0.804	0.812	0.882	0.837	4.767
7	0.874	0.828	0.79	0.885	0.799	0.769	-0.63
8	0.787	0.65	0.745	0.648	0.71	0.782	5.4
9	0.851	0.834	0.878	0.818	0.874	0.821	4.33

thread was connected to the slider in order to measure frictional parameters. The conventional test results for nine fabrics are shown in Table 3.

The data obtained in two test series were compared by using regression analysis. Dynamic part of data analysis lead to the correlation coefficient. This is shown in Table 4 for two types of the tests.

4. CONCLUSIONS

In this paper, a new method for measuring frictional properties of woven fabric has been presented and correlation of coefficient was obtained from the fitted line in dynamic friction region. This shows that the scattering of information about the regression line is 7.6% less for the new test method compared with the previous one. Therefore, it is concluded that the sliding conditions are much improved and are tending toward an optimal condition.

5. ACKNOWLEDGEMENT

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