Surface Frictional Resistance of Fabrics Woven from Filament Yarns

WITOLD ŻUREK, DANUTA JANKOWIAK, AND IWONA FRYDRYCH

Politechnika Łódzka, Lodz, Poland

ABSTRACT

The differences in frictional forces acting between fabrics woven from filament yarns are dependent on the morphology of the fabrics and the rubbing direction. When one fabric is moved across a second stationary fabric and the projecting yarn waves of one of the fabrics is rubbed perpendicular to the yarn axes orientation, the Howell's characteristics of frictional resistance for the fabric and yarn have similar values.

The friction of a fabric on itself or on another fabric has a significant effect on fabric performance and comfort of the user [3]; therefore, it is important to assess friction quantitatively as well as the factors that may affect friction.

Whereas many papers have been published on the friction of a fiber or yarn on itself and on other surfaces, those dealing with fabric friction are few and mainly concerned with test procedures. As for attempts to shed light on the variation of friction as a function of fabric morphology, there is really only one paper by Wilson [7].

In view of the importance of the frictional properties of textile fabrics for certain aspects of use, we have attempted in this paper to explain how the morphology of a fabric and the forces of friction of the yarn on itself may affect the fabric-on-fabric friction properties and how the knowledge may be of use to the fabric designer.

Assumptions

FABRIC MORPHOLOGY AND FRICTIONAL PROPERTIES

The frictional resistance for fabric, which manifests itself when a fabric is being slid upon itself, is similar to that produced when other materials are rubbed against one another [3], a result of overcoming the resistance of adhesion at the contact points of the surfaces, of overcoming the resistance of the irregularities of the surfaces and, at high loads, of destruction of the surface microprojections or of grooving troughs in the surfaces. As far as textile fabrics are concerned, only the first two phenomena are likely to occur.

Let us consider a plain woven fabric having the same filament yarn in its warp and weft, the warp and the weft differing only in the crimp ratio of yarn (the crimp ratio of warp yarn w_w is less than the crimp ratio of weft yarn w_f). In this fabric, the plane tangent to the weft peaks is elevated above the plane tangent to the warp peaks (see Figure 1).

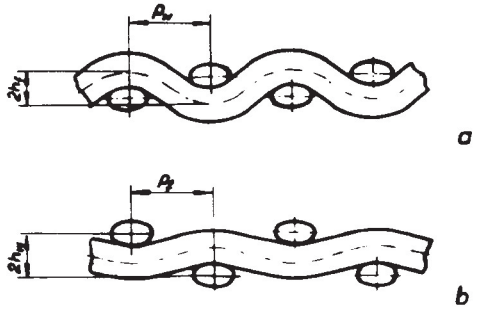


FIGURE 1. Schematic representation of the cross section of a plain-woven fabric (a) along the weft and (b) along the warp.

If specimens of such a fabric are placed on parallel flat plates and if two specimens of the fabric are moved with respect to each other along the weft (Figure 2a), the contact points occur along the weft yarn axis and the possible ascends and descends of the upper fabric are gentle. The frictional forces here are largely dependent on the direction of rubbing (i.e., whether friction occurs between yarns of the

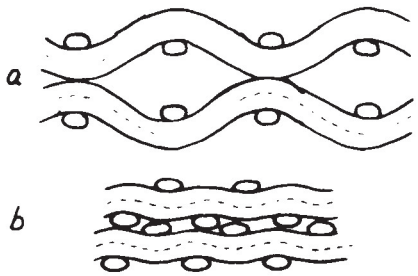


FIGURE 2. The contact points of fabric in longitudinal fabric-on-fabric friction (a) along the weft and (b) along the warp. The dotted traces represent sections along the axis of the neighboring warp or weft thread.

© Textile Research Institute

0040-5175/85/55002-113$2.00

UATP 1010

same system along their axes, or between yarns of one system and those of the other system in a direction perpendicular to the axis of the other system).

In friction along the warp (Figure 2b), the weft yarns of the upper fabric are obstructed by the weft yarns of the lower fabric, and the ascending distance of the upper fabric is shorter; therefore, a higher force is required to perform the ascent.

Such an ideal model is, of course, an approximation of fabrics woven from filament yarns. With fabrics woven from spun yarns, it is necessary to take yarn fineness irregularity into account. The fabric has a different thickness at each crossing of the weft and warp [9]. There will be fewer actual contact points between the two fabrics but additional resisting forces may be produced by the projecting fibers.

FRICTION OF FABRICS IN WEAR AND TEST METHOD

To be correct, a test method must simulate or reproduce the essence of the analyzed phenomenon. When a fabric is dragged on itself or on another solid substance, the motion involved is almost always a reciprocating motion. Hence, the method used to analyze fabric friction should reproduce the reciprocating motion; however, a majority of the published studies of fabric friction have used methods based on the unidirectional motion principle [6]. In analyzing the results obtained by a such motion method, Dreby [1] found that when a fabric was repeatedly, dragged on another fabric in the same direction, a reduction in the friction force occurred. About ten cycles of the instrument were necessary to bring the frictional force to a stable level. This observation initiated the practice of testing the friction of fabrics by rubbing them several times in the same direction and recording the frictional force or coefficient of friction during the tenth movement of the fabric.

Consistent with the assumption of reciprocating motion in friction, we have developed a modification of Dreby's method [8]. The reciprocating motion is imparted to the carriage holding the upper fabric. With the modified instrument, no variation of the frictional force occurs, since the effect of the interface fibers being "arranged" during motion in one direction is removed during motion in the reverse direction.

EXPERIMENTAL MATERIAL

In order that we might better visualize the effect of the morphology of a fabric on its frictional properties, we used six fabrics woven entirely from filament yarns as experimental material. Four of the fabrics were plain woven and two had a sateen weave (Figure 3). The purpose of selecting filament yarn fabrics was to eliminate any possible effect of structural non-uniformity associated with variation of yarn diameter, which is normally the case with fabrics woven from spun yarns. Three of the fabrics were woven from polyamide filament yarn, one from polyester filament yarn, one from viscose rayon, and one from acetate rayon. Before measurement of the frictional force, the fabrics were finished under normal industrial conditions. The characteristics of the fabrics are given in Table I.

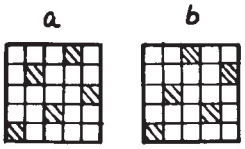


FIGURE 3. The satin weave of fabric I and II.

MEASURING FRICTIONAL RESISTANCE

For measuring the frictional resistance of the fabrics, we used a special modification [8] of the Instron tester. The modified instrument is shown schematically in Figure 4.

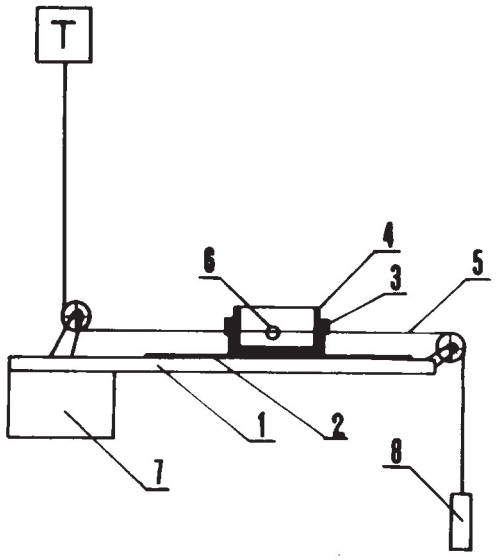


FIGURE 4. Diagram of the device for measuring the frictional force of fabrics.

In the modified Instron tester, a flat plate (1) is fixed to the crosshead and the lower fabric (2) is mounted on the flat plate. A carriage (4), which functions as a holder of the upper fabric (3), is placed on the lower fabric. During measurement, the lower

TABLE I. Structural parameters of the fabrics.

Fabric	Type of weave	Type of yarn: Warp	Type of yarn: Weft	Linear density Tt, mg/m: Warp	Linear density Tt, mg/m: Weft	Twist m^{-1}: Warp	Twist m^{-1}: Weft	Ratio between yarn length and corresponding dimension of fabric, W: Warp	Ratio between yarn length and corresponding dimension of fabric, W: Weft	Pitch, mm: Warp	Pitch, mm: Weft
I	sateen ¼ [2]	polyester filament	polyester filament	9.2	18.8	150	0	0.025	0.015	0.150	0.385
II	sateen ¼ [3]	polyamide filament	polyamide filament	2.2/1	7.8/17	0	0	0.008	0.0085	0.076	0.295
III	plain	polyamide filament	polyamide filament	7.8/17	7.8/17	0	0	0.017	0.010	0.250	0.293
IV	plain	polyamide filament	polyamide filament	7.8/17	7.8/17	0	0	0.017	0.005	0.260	0.320
V	plain	acetate rayon	acetate rayon	11.0/26	15.6/26	80	90	0.030	0.004	0.240	0.380
VI	plain	viscose rayon	viscose rayon	11.0	20.0	0	150	0.056	0.010	0.22	0.34

and the upper fabrics are identical. A filament (5), to which a pull rod (6) is fixed, is mounted so that it freely traverses the carriage. One end of the filament is attached to a strain-gauge dynamometer T, the other end of the filament being counterbalanced by means of a weight (8) providing a load greater than the highest frictional resistance.

During the downward movement of the crosshead (7), the filament (5) and pull rod (6) are traveling in the lefthand direction until the pull rod contacts the left wall of the carriage. From that moment, the carriage and the upper fabric are moved leftward until the crosshead reaches the present gauge length. Then the direction of the crosshead is reversed, and the filament and pull rod travel in the righthand direction until the pull rod contacts the right wall of the carriage. From that moment the carriage is moved rightward by the counterweight (8).

The frictional forces measured by the strain-gauge dynamometer during the movements of the carriage are recorded on the recorder chart. Graphical representations of the forces are shown in Figure 5. With unchanged carriage reversal points, the force-distance curves are reproducible with high accuracy.

During the first stage in which the pull rod moves freely inside the carriage, the strain gauge records a force F_1' equal to the mass of the weight (8) G and block frictional force F_b:

$$F_1' = G + F_b \quad . \tag{1}$$

When the filament tension has reached its maximum value F_{1s} the carriage begins to move. The force F_{1s} consists of static frictional force T_s, mass of the weight G, and block frictional force F_b (F_b being assumed to have a constant value):

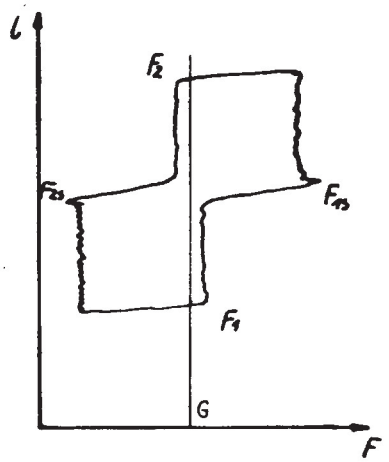


FIGURE 5. Variation of the frictional force during reciprocating motion of carriage.

$$F_{1s} = T_s + G + F_b \quad . \tag{2}$$

As the crosshead continues to move, the tie rod tension decreases until F_{1k} because of a decrease in the frictional force to T_k.

During return of the crosshead, the load on the filament from the lefthand side is reduced to the value

$$F_2' = G - F_b \quad . \tag{3}$$

With further movement of the carriage, the filament tension is slightly increased since the dynamic frictional force T_k is somewhat lower than T_s. Upon simple transformation, frictional force is obtained as given by

$$T_{s(k)} = \frac{1}{2}[F_{1s(k)} - F_{2s(k)}] - \frac{1}{2}(F_1' - F_2') \quad . \tag{4}$$

In measurement, the weight of the carriage alone or of the carriage loaded with one of the three weights was the force that pressed the carriage to the base plate. Thus four load levels were available: A – mass of the carriage alone – 66.9 g, B – mass of the carriage plus weight 1 – 194.9 g, C – mass of the carriage plus weight 2 – 381.9 g, and D – mass of the carriage plus weight 3 – 1010.9 g. The operating (lower) surface of the carriage was 60 × 60 mm, the dimensions of the lower fabric were 150 × 250 mm, the carriage travel was 100 mm, and the crosshead speed was 50 mm/minute.

To obtain characteristics of the frictional resistance for each load level, the relation between the frictional force and mass of the carriage (alone or with weights), G_j was calculated from the equation

$$f_{fj} = \frac{T_j}{G_j} \quad . \tag{5}$$

Five measurements were performed for each load level. The extreme force at the start of the carriage was adopted as the static frictional force, and the mean force calculated from the maximum and minimum forces recorded during a given travel of the carriage was adopted as the kinetic frictional force.

Frictional Resistance of Yarns

In order to learn to what extent the frictional resistance of the fabric is affected by the frictional properties of the component yarns, we also measured the frictional resistance of the yarns. For this, we used a modification of the friction-on-block (capstan) method using the Instron tensile tester provided with the special device shown in Figure 6.

A frame (2) is attached to the crosshead (1) and provided with two rollers (3), each roller having projections (teeth) on its entire surface. Using these projections, the yarn is wound up on the rollers parallel to the roller axes. The second sample of yarn goes through the rollers so that the yarn on the rollers and the yarn going through the rollers are perpendicular to each other. The upper end of the yarn is clamped to the load cell (5), and the lower end is loaded with a weight (9). This weight has an interesting clamp: a rod (6) is mounted horizontally on the clamp (7) of the weight (9). The rod is arranged to move in the proximity of a fork (8), which is coupled to the frame (2). The function of the fork is to prevent the yarn from untwisting.

As the crosshead moves down, the yarn sample moves on the rollers and the Instron tester rejects a force acting on a load cell. This force is equivalent

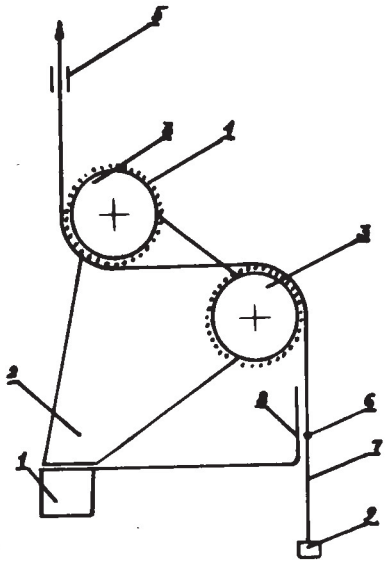


FIGURE 6. Arrangement for measuring yarn friction.

to joint action of the weight (9) and frictional resistances on the upper and lower rollers.

If we assume that Euler's equation for friction on a block is applicable here, the frictional force acting on the load cell would be given by

$$F_1 = Ge^{\pi f_y} \quad , \tag{6}$$

where G is the load of the weight (9), and f_y is the coefficient of friction of the yarn on itself. With the crosshead moving up, the force would be

$$F_2 = Ge^{-\pi f_y} \quad . \tag{7}$$

From the relationship between the two magnitudes it follows that

$$f_y = \frac{1}{2\pi} \ln \frac{F_1}{F_2} \quad . \tag{8}$$

The special device has rollers 30 mm in diameter; the masses of the weights (9), respectively, are 11.2 g, 19.0 g, 29.0 g; crosshead speed is 50 mm/minute; and crosshead travel is 100 mm.

Five measurements were performed for each case. The extreme value of frictional force in a given cycle was adopted as the static frictional force, and the mean frictional resistance in a given frictional passage of yarn was adopted as the kinetic frictional force.

Experimental Results

To obtain a full image of the frictional resistance of the fabrics, we used the following four combinations of rubbing direction and fabric orientation: warp-warp (w/w), warp-weft (w/f), weft-warp (f/w), and weft-weft (f/f). In this nomenclature, the first member

denotes the system of threads of the base fabric, which is parallel to the direction of the motion of the carriage, and the second member denotes the system of threads of the fabric attached to the carriage and parallel to the direction of its motion. The measurements were performed on five fabric specimens; for each specimen the carriage was moved three times in both directions.

The results of the measurements are presented in Figures 7, 8, and 9. The coefficients of static friction for the four combinations are w/w – 0.13 to 0.68, w/f – 0.16 to 0.80, f/w – 0.16 to 0.73, f/f – 0.41 to 1.25, and the coefficients of kinetic friction are w/w – 0.12 to 0.57, w/f – 0.11 to 0.68, f/w – 0.12 to 0.68, f/f – 0.26 to 1.18.

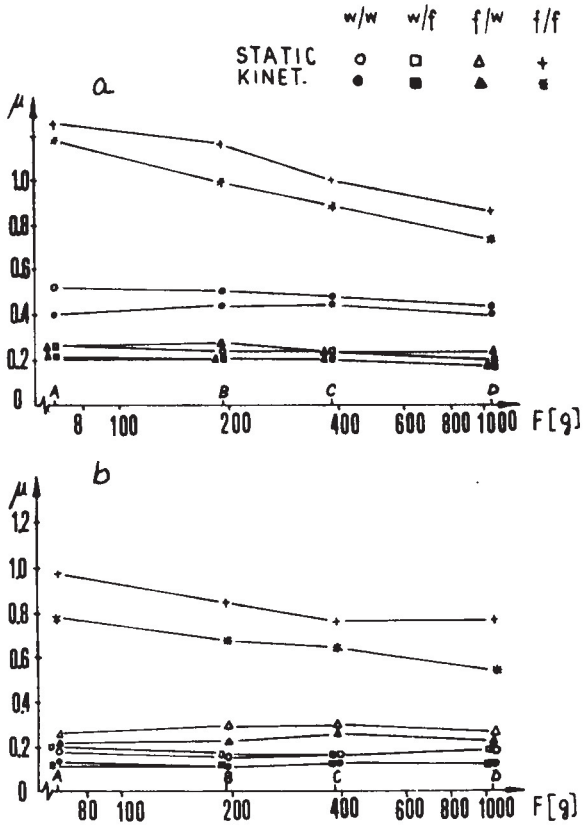


FIGURE 7. Mean values of the coefficients of static and kinetic friction for (a) fabric I and (b) fabric II.

We also measured the frictional resistance of the yarns using the combinations warp/on roller/—warp/ in clamps (w/w); warp-weft (w/f); weft-warp (f/w); and weft-weft (f/f). The results are presented in Figures 10, 11, and 12. The coefficients of static friction for these combinations are w/w – 0.16 to 0.25, w/f – 0.16 to 0.28, f/w – 0.16 to 0.26, f/f – 0.16 to 0.45, and the coefficients of kinetic friction are

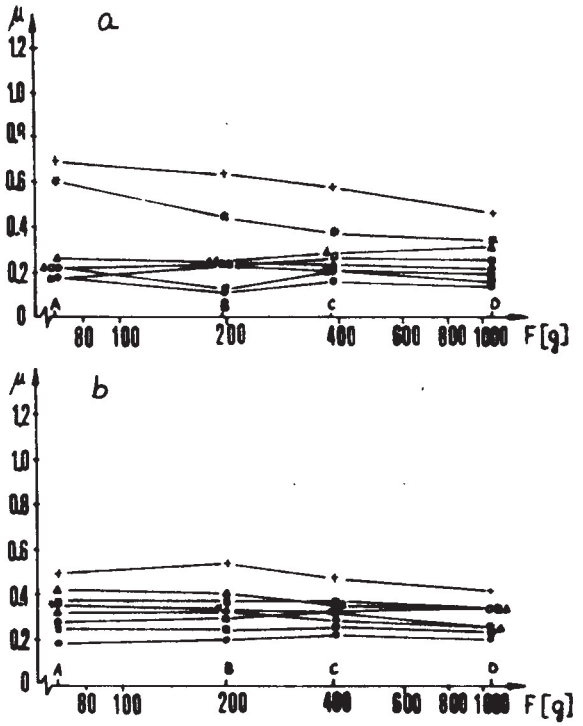


FIGURE 8. Mean values of the coefficients of static and kinetic friction for (a) fabric III and (b) fabric IV.

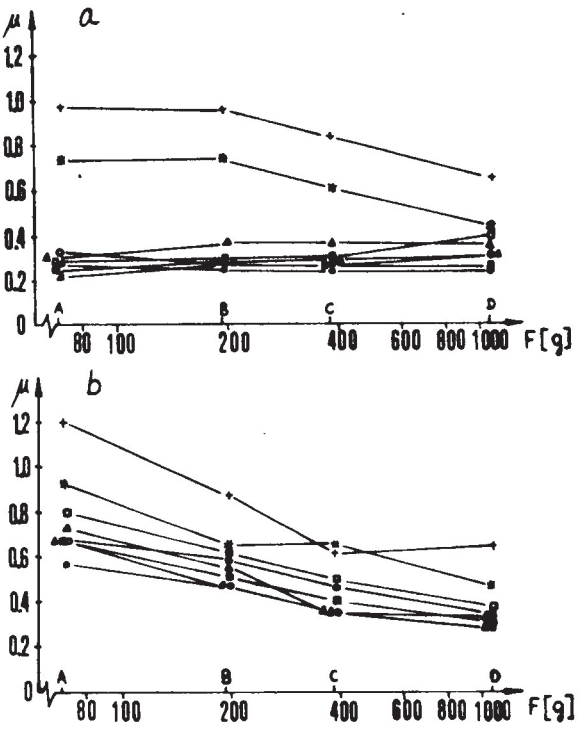


FIGURE 9. Mean values for the coefficients of static and kinetic friction for (a) fabric V and (b) fabric VI.

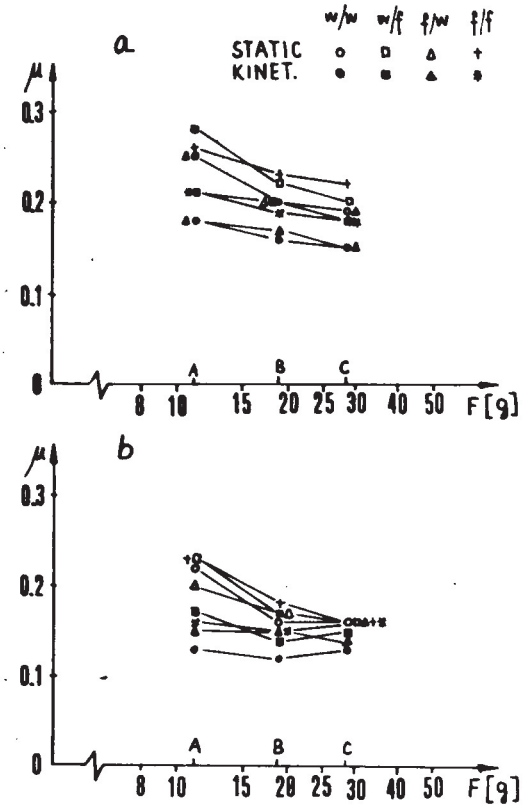


FIGURE 10. Results of the coefficients of static and kinetic friction of yarn removed from (a) fabric I and (b) fabric II.

w/w – 0.13 to 0.21, w/f – 0.15 to 0.25, f/w – 0.14 to 0.20, f/f – 0.15 to 0.37.

The coefficients of friction represented in Figures 7, 8, and 9 agree with the results obtained by Wilson. The highest values are those representing friction along one of the thread systems, *i.e.*, if the "base" fabric and the fabric on the carriage were so oriented that the rubbing of the yarns occurred in the weft direction. We obtained relatively low values for some alternate combinations (warp-weft, weft-warp), and in these cases the numerical values of the coefficients of friction were similar.

Generally, the coefficient of friction decreases with increased pressure of the upper fabric on the base fabric, although in the case of the polyamide filament fabrics, this relationship occurs only in the combination "weft-weft," while in the remaining combinations of fabric-on-fabric friction the value of the coefficient is only slightly affected by the applied pressure. We have observed analogous phenomena for the coefficient of yarn-on-yarn friction. The coefficient is thus affected by a variation of load in the case of the polyamide yarns, but in the remaining cases increased pressure results in only a slight decrease in the coefficient. Molgaard [4] observed a similar phenomenon.

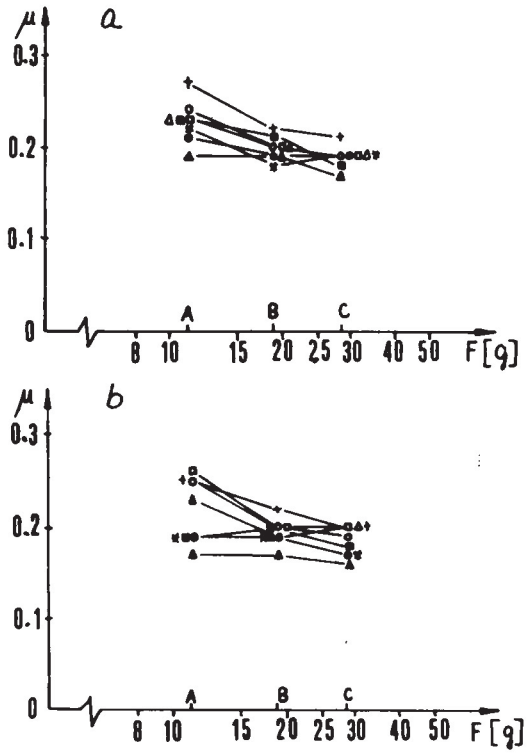


FIGURE 11. Results of the coefficients of static and kinetic friction of yarn removed from (a) fabric III and (b) fabric IV.

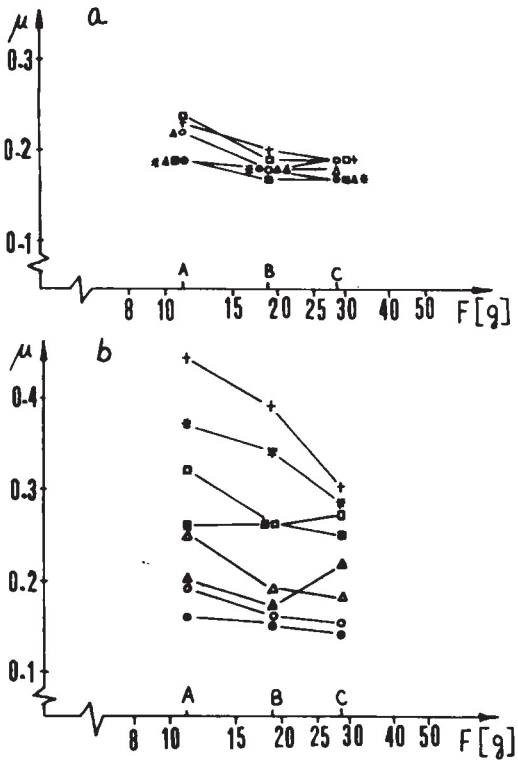


FIGURE 12. Results of the coefficients of static and kinetic friction of yarn removed from (a) fabric V and (b) fabric VI.

If we compare the values of the coefficients of friction of the yarns rubbing themselves and of the fabrics, we find that the fabric coefficients of friction are almost invariably higher than those of the corresponding yarns rubbing on themselves. On the other hand, we have observed large differences between the coefficients of friction of the yarns and the coefficients related to selected directions of rubbing of the fabrics on themselves (combination weft-weft).

The variation of the coefficients of friction of the fabrics rubbing on themselves with a change in the rubbing direction is accounted for by the previously mentioned interference between the peaks of yarns of the same system. It is the easiest to demonstrate if we analyze the structure of plain woven fabrics.

According to Peirce's equation [5] the yarn axis wave height in a plain woven fabric is

$$2h_w = \frac{4}{3} p_f \sqrt{w_w} \quad , \tag{9}$$

where p_f = pitch of the weft yarn and w_w = crimp ratio (*i.e.*, linear ratio of yarn length to corresponding fabric dimension) of warp yarn. The distance between the planes tangent to the warp and to the weft is correspondingly

$$G_w = 2h_w + 2b_w \quad , \tag{10a}$$

$$G_f = 2h_f + 2b_f \quad , \tag{10b}$$

where $2b_w$ = the smaller diameter of the warp cross section and $2b_f$ = the smaller diameter of the weft cross section. It is therefore evident that

$$h_w + h_f = b_w + b_f \quad . \tag{11}$$

If the yarns have different linear densities then, assuming that in the fabric the yarns of either system have similar porosities, we obtain the following relation:

$$\frac{b_w}{b_f} = \sqrt{\frac{Tt_w}{Tt_f}} = k \quad , \tag{12}$$

where Tt_w and Tt_f are linear densities of warp and weft, respectively.

The values of p, w, and Tt being known from the analysis of the fabrics and yarns, we can calculate h and k, and

$$b_w + b_f = kb_f + b_f = (k+1)b_f = h_w + h_f \quad , \tag{13}$$

hence

$$b_f = \frac{1}{k+1}(h_w + h_f) \quad , \tag{14a}$$

and

$$b_w = \frac{k}{k+1}(h_w + h_f) \quad , \tag{14b}$$

and finally,

$$G_w = 2h_w + \frac{2k}{k+1}(h_w + h_f) \quad , \tag{15a}$$

$$G_f = 2h_f + \frac{2}{k+1}(h_w + h_f) \quad . \tag{15b}$$

The values of G_w and G_f, as calculated from the equations above, and the values of the coefficients of friction of the fabrics for two combinations (w/w, f/f) as obtained experimentally are given in Table II.

In all cases, warp elevations are dominant and therefore in relative motion along the weft, there will be intereference between the elevations leading to increased frictional resistance, this being reflected by the high values of the coefficients of friction.

TABLE II. Values of G_w and G_f and the corresponding coefficients of friction for the plain woven fabrics.

Fabric	G_w, mm	G_f, mm	Load level	Coefficient of static friction w/w	Coefficient of static friction f/f
III	0.094	0.076	A	0.23	0.69
			D	0.17	0.46
IV	0.096	0.065	A	0.28	0.50
			D	0.34	0.41
V	0.136	0.071	A	0.31	0.97
			D	0.30	0.64
VI	0.167	0.104	A	0.68	1.20
			D	0.35	0.65

Analysis of the coefficients of friction calculated from the Amontons and Euler equations shows that their values decrease with increased unit pressure. We have therefore, attempted to use the parabolic relationship between unit pressure q and unit frictional force t [2] in the form

$$t = Cq^n \quad , \tag{16}$$

where C and n are constant values determined experimentally.

In this experiment, the total length of the projection of the yarn axis in the fabric on the plane parallel to the fabric measured in one direction is

$$L_y = \frac{60 \cdot 60}{p} \quad . \tag{17}$$

As the length and width of the sample are each 60 mm, so the number of threads is $60/p$ (p is the pitch of the thread); therefore the unit pressure is

$$q = \frac{N}{L_y} \quad , \tag{18}$$

where N = the load pressing the upper fabric to the base fabric. This is a conventional quantity, since the actual length over which yarns are in contact during the rubbing motion is much lower (for plain woven fabrics it does not exceed 20%).

For the yarns, the unit pressure from the pulling side, if the crosshead is travelling down, is

$$q_0' = \frac{G}{R} \quad , \tag{19a}$$

where G = mass of the weight and R = radius of the block on which yarn is wound. From the pulled side, it is

$$q_1' = \frac{F_1}{R} \quad , \tag{19b}$$

where F_1 = force recorded on the strain gauge. If the crosshead is traveling up,

$$q_0'' = \frac{F_2}{R} \quad , \tag{19c}$$

$$q_1'' = \frac{G}{R} \quad . \tag{19d}$$

In accordance with Howell's equation

$$T_{1i}^{(1-n)} = T_{0i}^{(1-n)} + (1 - n)C\varphi R^{(1-n)} \quad , \tag{20a}$$

or

$$q_{1i}^{(1-n)} = q_{0i}^{(1-n)} + (1 - n)C\varphi \quad , \tag{20b}$$

where T_1 = final force ($T_1' = F_1$; $T_1'' = G$), T_0 = initial force ($T_0' = G$; $T_0'' = F_2$), i = index of load level imposed on yarn (i = 1, 2, 3 because m_1 = 11.2 g, m_2 = 19.0 g, m_3 = 29.0 g), φ = the angle subtended over the rollers, and R = radius of the block on which yarn is wound. In the arrangement used here $\varphi = \pi$.

For our purposes it may be useful to know in what relationship the value of coefficient of friction from Euler's equation remains the same as that derived from Howell's equation. From Euler's equation, P_{0i} for a given preload is given by

$$P_{1i} = P_{0i}e^{f_i\pi/2} \quad . \tag{21}$$

If either side of the equation is divided by R and $e^{f_i\pi/2} = x_i$ then

$$\frac{P_{1i}}{R} = \frac{P_{0i}}{R} e^{f_i\pi/2}$$

$$q_{1\cdot i} = q_{0\cdot 1} \cdot x_i \quad . \tag{22}$$

Substituting the value to Equation 20b, we obtain

$$(q_{0\cdot i} \cdot x_i)^{(1-n)} = q_{0\cdot i}^{(1-n)} + (1 - n)C\pi \quad , \tag{23}$$

therefore

$$q_{0\cdot i}^{(1-n)}[x_i^{(1-n)} - 1] = (1 - n)C\pi \quad . \tag{24}$$

If we use the equation for particular load levels on yarn, we obtain

$$q_{0\cdot 1}^{(1-n)}[x_1^{(1-n)} - 1] = q_{0\cdot 2}^{(1-n)}[x_2^{(1-n)} - 1] \quad , \tag{25a}$$

$$q_{0\cdot 2}^{(1-n)}[x_2^{(1-n)} - 1] = q_{0\cdot 3}^{(1-n)}[x_3^{(1-n)} - 1] \quad . \tag{25b}$$

Knowing the values of $q_{0\cdot 1}$, $q_{0\cdot 2}$, x_1, and x_2, we can solve Equation 25a by trial and error. If the value of n obtained this way is substituted to Equation 25b we can learn whether the assumptions associated with Equation 20b have been correct. The results obtained using this procedure are presented in Table III.[1]

Analysis of the data indicates that there is agreement between values of the frictional characteristics of the fabrics and of the yarns. We observed differences between the values only for the viscose rayon fabrics. This may be due to the specific behavior of these fabrics in reaction to increasing pressure.

Discussion and Conclusions

Our investigation has shown that the frictional resistance of fabrics woven from filament yarns is dependent on both rubbing direction and fabric mor-

[1] The calculation for static friction of the yarns is based on the use of weights 19.0 g and 29.0 g, and for kinetic friction on weights 11.2 g and 29.0 g.

TABLE III. Values of C and n of the investigated yarns and fabrics.

	Yarns (rubbing direction, w/w)				Fabrics (rubbing direction, w/f)			
	Static		Kinetic		Static		Kinetic	
Fabric	C	n	C	n	C	n	C	n
I	0.25	0.90	0.32	0.83	0.29	0.94	0.24	0.94
II	0.17	1.00	0.16	1.00	0.20	0.97	0.13	0.98
III	0.24	0.88	0.22	0.89	0.22	1.06	0.18	1.04
IV	0.24	0.88	0.21	0.88	0.43	0.94	0.32	0.93
V	0.19	1.00	0.21	0.88	0.24	1.11	0.21	1.06
VI	0.23	0.85	0.21	0.86	1.12	0.73	1.02	0.71

phology. The frictional force is highest when the direction of motion of the moving fabric is perpendicular to the orientation of the axes of the dominating peaks of either fabric; it is the lowest if the direction of motion is parallel to the orientation of the axes of the dominating peaks of the moving fabric and perpendicular to the orientation of the axes of the dominating peaks of the base fabric.

Variation of pressure at the contact points of the interface has little effect on the frictional resistance, and if the frictional resistance is generated by displacement of one system of threads versus threads of the same system, but oriented perpendicular to the first threads, then the parameters C and n of the equation $t = Cq^n$, which interrelates unit friction t with unit pressure q, are similar for the fabric and the yarn.

Our results permit the following conclusions: The morphology of fabrics has a decisive effect on the frictional resistance occurring in friction of the fabrics, the highest frictional forces being recorded when the orientation of the axes of the projecting yarns (peaks) of both fabrics is perpendicular to the rubbing direction and the lowest when the axes of the projecting yarns of the fabrics are perpendicular to each other. With the projecting yarn waves of one of the thread systems (in our study it was the warp) being rubbed in a perpendicular relation to the orientation of the yarn axes, the values of the parameters describing the frictional resistance of the fabrics were similar to those of the parameters describing the friction of the yarns on themselves. Variation of the pressure at the interface between the yarns only slightly affects the values of the coefficient of friction of the fabrics and of the yarns on themselves.

Literature Cited

1. Dreby, E. C., A Friction Meter for Determining the Coefficient of Kinematic Friction of Fabrics, *J. Res. Nat. Bur. Stand.* **31**, 237 (1943).
2. Howell, M. G., The General Case of Friction of a String Round a Cylinder, *J. Textile Inst.* **44**, T359 (1953).
3. Howell, H. G., Mieszkis, K. W., and Tabor, D. "Friction in Textiles," Textile Institute and Butterworths Scientific Publications, 1959.
4. Molgaard, J., Hydrodynamic Lubrication of Yarns and Fibers, *Textile Res. J.* **32**, 612 (1962).
5. Peirce, F. T., Geometry of Cloth Structure, *J. Textile Inst.* **28**, T45 (1937).
6. "Textile Metrology," vol. IV, WNT, Warsaw 1973.
7. Wilson, D., A Study of Fabric-on-Fabric Dynamic Friction, *J. Textile Inst.* **54**, T143 (1963).
8. Żurek, W., Frydrych, I., and Miedzińska, H., A New Method for Determination of the Friction Factor Between Woven Fabrics, *Przegl. Włók.* **35**, 44 (1981).
9. Żurek, W., and Kopias, K., "The Structure of Flat Textile Fabrics," WNT, Warsaw, 1983.

Manuscript received September 20, 1983, accepted June 1, 1984.