Effects of Sled Velocity on Fabric Friction

J. O. Ajayi*, H. M. Elder**, K. A. Bello***
E. G. Kolawole***, M. I. Darma***

Abstract

The influence of velocity of sliding on some new frictional parameters of weft pile fabrics is reported. The frictional amplitude diminish as the velocity of motion increased. The kinetic frictional resistance also diminish initially, and then increased as the velocity of sliding increased. The initial decrease in resistance to motion is attributed to viscoelastic effects while the increase in resistance to motion at higher speeds is ascribed to mechanical interlocking of surface structure. The amplitude of frictional resistance and number of peaks are shown to be related to some pertinent fabric properties such as cord height and number respectively.

(Received June 17, 1996)

(Accepted for Publication July 4, 1998)

1. Introduction

In some systematic studies of frictional properties of fabrics¹⁻⁴⁾ the effects of fibre content¹⁾, yarn mechanical properties²⁾, fabric structure³⁾, and finishing treatments⁴⁾ were considered. The influence of experimental variables, such as normal load, area of contact and the nature of sled surfaces were investigated⁵⁾. We have not as yet considered in detail the influence of velocity of sliding on some new frictional parameters such as frictional resistance, amplitude and number of peaks of the stick-slip motion. Since these parameters are related to fabric handle¹⁻⁴⁾ and quality¹⁾ their consideration was thought useful.

In some earlier investigations, Nishimatsu and Sawaki^{6,7)} studied the frictional properties and handle of some warp pile (terry towel) cotton fabrics. These authors considered the effects of normal load⁷⁾, area of contact⁶⁾ relative humidity

and velocity of sliding⁷⁾. They found that the frictional resistance increased as the normal load and area of contact increased. The frictional resistance diminished at first (0.5–5.0m/s), and then increased again as the velocity of sliding increased⁷⁾. Although these authors did not explain their observations, it is reasonable to assume that an increase in velocity implies a reduction in the time of contact between the rubbing surfaces. For viscoelastic materials such as fabrics, the deformation is expected to increase as the time of contact increases⁸⁾ therefore, an increase in sled velocity should result in a decrease in frictional resistance. This hypothesis is tested in this work.

Nishimatsu and Sawaki⁷⁾ also showed the frictional traces of fabrics at different speeds. Clearly, their results show that the stick-slip pulses (amplitude) gradually diminished as the speed increased. Since the effects of velocity on some of the stick-slip parameters, such as number of

*Abubakar Tafawa Balewa University, Industrial Chemistry Programme, P. M. B. 0248, Bauchi.

**University of Strathclyde, Department of Pure & Applied Chemistry, Fibre and Textile Research Unit, 295 Cathedral Street, Glasgow, G1 1XL, U. K.

***Ahmadu Bello University, Department of Textile Science & Technology, Zaria, Nigeria.

peaks, amplitude and frictional resistance, are not frequently a subject of experimental scrutiny, they are considered in this investigation. However, before the discussion of experimental results, it is pertinent to examine the theoretical basis of the stick-slip phenomenon, and the manner in which it is affected by the velocity of sliding.

2. Theoretical Background

Theoretically, the frictional resistance between two bodies depends upon the intimacy of contacts¹⁾, yield pressure⁵⁾, shear strength of the junction⁸⁾ and the velocity of sliding^{1, 8, 12)}. Any experimental variation that alters any one or more of these factors would also lead to an alteration of frictional properties. Considering a general case in which a sled of mass m , sliding over a fabric with a uniform velocity v , and suppose the sled is driven by a constant rate of elongation tester which acts as an elastic system¹²⁾. The spring deflexion of the load cell of the tester is a measure of the frictional resistance F . Assuming the spring constant of the load cell is c , the spring displacement x of the load cell is expressible by the following equation

$$F = -cx \quad (1)$$

(the negative sign is indicative of a frictional resistance acting in opposition to an increasing x). Assuming there is no damping, the equation of motion in free oscillation is given by :

$$m \frac{d^2x}{dy^2} = -cx \quad (2)$$

This is a simple harmonic equation of frequency f , where

$$f = \frac{1}{2\pi} \sqrt{\frac{c}{m}} \quad (3)$$

Assuming the asperities on the sled and fabric surfaces intermesh, as is likely to be the case in weft pile corduroy fabrics³⁾, so that the two surfaces travel together without relative motion until the force on the fabric is equal to the static friction, Fs ;

$$Fs = \mu N \quad (4)$$

where

$$\mu = \frac{1}{N_2 - N_1} \int_{N_1}^{N_2} (F/N) \cdot dF \quad (5)$$

$$F = KN^n \quad (6)$$

μ = coefficient of friction

N = normal load

K = frictional constant

n = frictional index.

Reference to the hypothetical stick-slip trace in Figure 1 will show that the deflexion by surface asperities is linear with time and deflexion BX is given by :

$$BX = \frac{Fs}{c} \quad (7)$$

At point B , slip will occur, therefore

$$\frac{d^2x}{dt^2} - FK = -cx \quad (8)$$

At the initial instant when $t=0$ (i. e. point B in Figure 1), the displacement x and the forward velocity dx/dt equals to v .

The solution to equation 8 is given by :

$$x = \frac{m}{c} [(Fs - Fk) (\cos \omega t + Fk) + \frac{\nu}{\omega} \sin \omega t] \quad (9)$$

where $\omega^2 = c/m$

If the relative displacement of the asperities on fabric surface is small compared to the mean velocity of the sled, the last term of equation 9 may be neglected, thus :

$$x = \frac{m}{c} [(Fs - Fk) \cos \omega t + Fk] \quad (10)$$

Thus the motion of the sled has the same natural frequency as before it comes to rest relative to that of the fabric, that is, it sticks again when $dx/dt = v$. If v can be neglected it may be considered that sticking recurs when $dx/dt = 0$, i. e. when $\omega t = \pi$. This will correspond to the natural period of the system. Substituting the value of ωt into equation 10 yields :

$$x = \frac{m}{c} (2Fk - Fs) \quad (11)$$

By definition^{1, 5, 8, 12)}, the amplitude or the size of the stick-slip, from peak to trough as depicted in Fig.1 is given by :

$$BC = BX - CY = Fs - F_0 \quad (12)$$

Table 1 Details of Weft Pile Fabrics

Fabric Code	Fibre Content		Fabric Sett (Tnd/cm)	Yarn Count (Tex)	Yarn Crimp (%)	Thickness (mm)	Weight (g/m ²)	NO. of ^b cords (per5cm)	Cord ^b Width (mm)	Cord ^c Height (mm)
	Base	Pile								
P P ₁ T	Polypropylene	Polyacrylics	30 16	31 16	9.8 16.3	2.88	340	(8)8	6.0	1.56
P P ₂ T	Cotton	Polypropylene	24 20	40 56	18.3 1.2	2.24	370	17	3.1	1.16
P P ₃ T	Polyacrylics	Polyacrylics	36 30	28 36	3.5 24.5	2.68	220	35	1.2	1.68
P P ₄ T	Cotton	Polypropylene	13 12	52 59	6.3 13.1	2.06	204	12	4.0	0.48
P P ₅ T	Cotton	Cotton	28 15	34 60	7.1 16.0	2.30	369	13	3.5	1.27

a Seww of base weave (plain)
b Test method : Cooke's micrometar (essentially a microscope with a traversing eye piece)
c Measured on the projection microscope (Text. Res. J., 62, 57, (1992)
P=Werp
T=Weft
Value in parenthesis refer to smaller cord

Fig. 1 Hypothetical stick-slip friction traces of fabrics.

Since x is equal to CY it is clear from equation 11 that the larger the value of Fk , the smaller the amplitude. In the limit when $F_s = Fk$, the amplitude becomes zero, so that the sliding remains steady, i. e. without the stick-slip characteristics. As Fk decreases, the amplitude increase in size. In the limit when Fk is zero, a swing beyond the zero position is envisioned. This will correspond to a theoretical maximum amplitude. Since the value of Fk could never be zero,

Fig. 2 Sketch of the fabric friction measurement on a flat horizontal platform
a=instron load cell
b=frictionless pulley
c=towing cord
d=sled covered with fabric
e=horizontal platform
f= fabric specimen,
g=connection to the bottom jaw.

Fig. 3 Relationship between the cord height and amplitude of the stick-slip friction traces.

the stick-slip amplitude could never be as pronounced. This hypothetical consideration suggests that an increase in the velocity of sliding is expected to decrease frictional resistance and amplitude of the stick-slip motion. This hypothesis is tested in this investigation.

3. Experimental

The purpose of this investigation is to demonstrate the relationship between some new frictional properties of fabrics and velocity. In some previous studies¹⁻⁷⁾, some links have been established between fabric friction and handle^{1-5, 15)}, such as smoothness³⁾. However, there is no systematic studies of the effects of sliding velocity on some of these new frictional parameters which also affect fabric handle. This paper also bridges this gap.

In some previous studies, Nishimatsu and Sawaki^{6, 7)} used pile fabrics in their frictional investigations. Similar fabrics are also used here to facilitate comparison of results. The fabric samples used in this investigation consist of five weft pile woven fabrics, with variation in number, height and width of fibre piles. Fabric mass range from 204g/m² to 370g/m², and thickness from 2.06mm to 2.88mm. Further details may be found in Table 1.

Fig. 4 Relationship between the number of cords and the number of stick-slip pulses.

3.1 Fabric Friction Measurement

For the friction measurements, we used an Instron tensile tester (model 1122) fitted with an appropriate friction assembly, i. e. aluminium platform, in accordance with the ASTM procedure¹³⁾. The principle of the measurements was based on the rectilinear motion of a sled over a horizontal platform (52×15cm). A light wooden sled (8×5cm) weighing 200g (i. e. 400N/m² pressure) was pulled at the required velocity by the Instron crosshead by means of an inextensible towing yarn passing over a frictionless pulley, as shown in Fig. 1. Both chart speed (5cm/min) and full scale deflection (200–2000g) were selected to give maximum reproducible frictional parameters.

The frictional properties of a fabric were measured by mounting a rectangular specimen (30×10cm) on a horizontal platform over which a sled covered with an identical fabric was drawn. The fabric on the platform was smoothed by hand and held under a slight tension by bull-dog clips, which ensured that the sample did not wrinkle or buckle during the tests. The fabric specimen on the sled was also slightly tensioned and fastened on the upper surface with double-sided tape. The fabric was tested across the direction of cords at different velocities. Fresh

Fig. 5 Effects of sled velocity on the kinetic frictional resistance of fabrics.

samples were used for all tests, and each fabric specimen was tested five times.

3.2 Expression of Results

The frictional parameters enumerated here were determined by trace analysis in accordance with a procedure used by several other investigators^{1-6, 7, 12}. Both static and kinetic frictional resistance were determined from the frictional trace. The highest peak at the beginning of motion was taken as the static frictional resistance^{1, 7, 12}. The mean of peaks and troughs (equivalent to drawing a straight line through the middle of the stick-slip pulses) was taken as the kinetic frictional resistance⁵.

The amplitude of frictional resistance was taken as the height (i. e. peak to trough) of the stick-slip pulses, excluding the first peak, which might be due to static effect^{1, 2, 4}. We then counted the number of distinctive peaks in a 5cm traverse of the sled^{1, 2, 5}.

4. Results and Discussion

Reference to Table 2 will show the frictional properties of fabrics at different velocities. The static frictional resistance of fabrics P₂ and P₅ increase, while that of fabric P₄ decrease, with an increase in the velocity of sliding. There was no

Fig. 6 Effects of sled velocity on the amplitude of the stick-slip traces.

consistent change in the static frictional resistance of fabrics P₁ and P₃. Perhaps this inconsistent result is due to the static effect which is partly governed by the intermeshing of fibre piles^{1, 3, 5} and partly by the viscoelastic nature of the fabric surface owing to compression^{8, 15}.

The number of stick-slip peaks (Table 2) is insignificantly affected by the velocity of sliding. This may be due to the relatively large size of cords on fabric surface, although the low range of velocities employed (5–20cm/min) in this study may also be a factor. The relationship between the cord height and the amplitude of the stick-slip frictional traces is depicted in Fig. 3. This shows an excellent linear correlation (regression coefficient=0.98). Similar results obtained in some earlier studies^{1, 2, 5} were attributed to an increase in the resistance to motion as the height of fibre pile increased. The relationship between the number of cords on fabric surface and the number of peaks of the stick-slip frictional trace is depicted in Fig. 4. The number of cords detected in all fabrics using the friction trace is lower than the theoretical maximum, i. e. the number of cords on the fabric surface. It is also interesting to note that the divergence of this agreement increases as the number of cords increase. This is not surprising because the

Table 2 Effects of sled velocity on frictional properties of fabrics
(normal pressure=400N/m², time of loading ; 3 min,
surface=fabric-on fabric)

Frictional parameters	Velocity (mm/min.)	Fabrics				
		P ₁	P ₂	P ₃	P ₄	P ₅
Fs (gf)	50	245	350	447	407	360
	80	315	375	467	430	373
	100	280	390	420	305	395
	200	280	405	450	350	440
Fk (gf)	50	200	340	370	297	305
	80	205	300	328	290	295
	100	230	310	327	252	325
	200	250	325	370	270	335
Fa (gf)	50	184	133	192	36	146
	80	133	104	126	11	143
	100	132	83	87	11	72
	200	95	31	33	12	60
Fn (per 5cm)	504	10	11	26	9	9
	80	10	11	26	8	9
	100	11	11	30	9	9
	200	9	11	28	8	9

Fs=Static frictional resistance

Fk=Kinetic frictional resistance

Fa=Frictional amplitude

Fn=Number of stick-slip peaks per 5cm. see fabric details in Table 1

greater the number of cords, the less the chances of mechanical interlocking of surface structure^{1, 5, 15)} i. e. cords, and ribs, the lower the number of cords detectable on fabric surfaces.

The results in Fig. 5 show that, with the possible exception of fabric P₁, in which the kinetic frictional resistance consistently increase, all other fabrics show an initial decline in resistance, followed by an increase. This agrees with the results of Nishimatsu and Sawaki⁷⁾ for fabrics, and several other workers for yarns⁸⁻¹¹⁾. However, this contradicts our earlier hypothesis in which it was wholly assumed that the kinetic frictional resistance is deformation controlled, and as such any increase in velocity should bring about a decrease in contact time of the sliding members which will in turn reduce the resistance to motion. It is likely that two separate factors are involved. The initial decrease at

low speed, i. e. longer contact time, may be governed by the visco-elastic nature of fabric surfaces. At higher speed, i. e. shorter contact time, the mechanical interlocking of surface asperities may be responsible for the increased resistance to motion. The reason for the consistent increase in kinetic frictional resistance of fabric P₁ as the velocity increased is not clear, but may be due to the predominant effect of mechanical interlocking over the viscoelastic-effect, thus the double cord nature of the surface (Table 1) may provide a good anchorage of the fibre pile and resistance to slippage at lower speed^{1, 10)}. Reference to Fig. 6 will show that the amplitude of the stick-slip motion diminish as the velocity increased. As stated earlier in equation 10, the motion of the sled is oscillatory, i. e. sticking will occur when $dx/dt=v$. At low values of v , i. e. $dx/dt=0$ or $\omega t=\pi$ in equation 10, slipping will occur,

Fig. 7 Typical frictional traces of fabric p_1 at different velocities.

thus the amplitude of frictional resistance, $F_s - F_o$, in equation 12, will diminish as the velocity of sliding increase. That is, any increase in the velocity of sliding should decrease the time of contact and hence reduce amplitude of resistance.

An important characteristic of corduroys in general is the ridginess of fabric surface. An examination of friction traces such as that shown in Fig. 7 permits such features to be objectively characterized and related to fabric handle and texture^{1-5,14,15)}. The effects of sled velocity on the stick-slip phenomenon can also be visually discerned. Fig. 7 shows a typical frictional resistance versus displacement curve for fabric P_1 . This Figure depicts that there are clearly two different kinds of cords on the sur-

face of fabric P_1 . The amplitudes yielded by these cords diminish as the velocity of sliding increase. This may imply a poorer discrimination at higher speeds. From the results of other fabrics examined, it was generally observed that the greater the stick-slip peaks, and their amplitudes, the higher the effects of velocity.

5. Conclusion

1. The number of cords in weft fabrics is linearly correlated with the number of peaks of the stick-slip motion. However, the number of stick-slip peaks detected by using the friction assembly is slightly lower than the actual number of cords on fabric surface. These results are attributed to the bluntness of the friction probe.

2. The amplitude of the stick-slip pulses, is linearly related to the cord height on pile fabrics.
3. The frictional amplitude diminishes while the number of peaks remain approximately constant as the velocity of sliding increases.
4. The kinetic frictional resistance decrease initially and then rise again as the velocity of sliding increase. The initial decrease was attributed to the viscoelastic properties of polymeric materials while the increase in resistance was attributed to mechanical interlocking of surface structure.

References

- 1) J. O. Ajayi, Ph. D. Thesis ; University of Strathclyde, Glasgow, 1988.
- 2) J. O. Ajayi and H. M. Elder ; J. Test. and Eva., **22**, 465, (1994).
- 3) J. O. Ajayi, Text. Res. J., **62**, 87, 1992.
- 4) J. O. Ajayi and H. M. Elder, J. Test. and Eva., **23**, 55, 1995.
- 5) J. O. Ajayi, Text. Res. J., **62**, 52 (1992).
- 6) T. Nishimatsu and T. Sawaki ; J. Text. Mech. Soc. Japan, **35**, T67, 1982.
- 7) T. Nishimatsu and T. Sawaki ; J. Text. Mech. Soc. Japan, **35**, T100, (1982).
- 8) H. G. Howell, K. W. Mieszkis and D. Tabor ; "Friction in Textiles" Butterworths and Textile Institute, London, 1959.
- 9) H. L. Roder ; J. Text. Inst., **44**, T247, (1953).
- 10) J. S. Olsen ; Text. Res. J., **31**, (1969).
- 11) A. R. Kalyanaraman ; Indian J. Text. Res., **13**, 1, (1988).
- 12) F. P. Bowden and D. Tabor, ; "Friction and Lubrication of Solids", Oxford Clarendon Press, London, 1964.
- 13) ASTM D1984, American Society for Testing and Materials.
- 14) M. U. Darma, M. Sc. Thesis ; Ahmadu Bello University, Zaria, 1992.
- 15) J. O. Ajayi and H. M. Elder ; J. Text. Inst., **86**, 600, (1995).