Frictional Study of Woven Fabrics: The Relationship between the Friction and Velocity of Testing

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ABSTRACT: A simple friction factor has been devised to characterize the frictional properties of textile materials. The friction factor enables universal comparisons among different textile materials. A poly(methyl methacrylate) sled has been used as a standard friction substrate to characterize the friction of a woven cotton fabric. The influence of the velocity of testing on the frictional characteristics has been studied in detail with the novel friction factor. This study elaborates the relationship between the speed of testing and the new fabric friction factor. © 2004 Wiley Periodicals, Inc. J Appl Polym Sci 92: 2420–2424, 2004

Key words: fibers; surfaces; structure-property relationships

INTRODUCTION

Very recently, there has been a major upsurge in the research on the frictional characterization of polymeric textiles, primarily because of the need for a standardized friction testing method.[1–7] Textile materials have been known to deviate from Amontons' law of friction.[8–11] This necessitates the evaluation of friction over a range of applied normal loads.[1–7,12] Howell and Mazur's[10] study of fiber friction proved the deviations from Amontons' law. A subsequent study by Wilson[8] further proved the failure of Amontons' linear friction law in fabrics. The importance of friction to the overall quality and mechanical properties of solid polymers and textiles has been well researched and documented.[13–15] Briscoe and Tabor[13] emphasized the relationship between the friction and wear properties of polymers and their bulk properties. Pierce[15] stressed the importance of friction to the overall quality or hand of fabrics, but he did not endeavor to experimentally measure the frictional properties. It is known that the frictional properties of textile materials depend on a number of testing parameters, such as the applied normal load, the area of testing, the speed of testing, and the nature of the contacting surfaces.[8,11,16–19] There is a plethora of literature available on the influence of applied normal loads and the area of testing on the frictional properties of textiles. However, there is a paucity of data on the influence of testing speeds on the frictional properties of textile materials. Studies by Ajayi[16] and Virto and Naik[20] have shown that the sliding speeds have a limited influence on the frictional properties. Most recently, Ramkumar et al.[21] studied the effects of sliding speeds on the frictional properties of nonwoven fabrics. Their results indicated that the frictional resistance increased with an increase in the speed of testing. However, this study did not attempt to examine the effect of sliding speeds on the frictional characteristics of a woven fabric. Woven fabrics are conventional and commodity textile products that are used in apparel goods. Therefore, it is necessary to evaluate the frictional properties of woven fabrics. Moreover, the influence of sliding speeds on the frictional properties of woven fabrics has to be evaluated because of the need for a standardized friction evaluation method.

This article reports on the effects of different sliding velocities on the friction of a cotton woven fabric at different applied load levels. A sliding friction apparatus has been used to measure the friction over a range of applied normal loads. Previous studies have used this apparatus to obtain two friction values: friction factor C and friction index n (nondimensional).[1–6,16,18] More recently, Ramkumar et al.[1] used this sliding friction apparatus to derive friction parameter K for characterizing the frictional properties of a set of 1×1 rib-knitted cotton fabrics. K is mathematically logical and overcomes the difficulty associated with the common friction parameter C. However, results from a very recent study have shown that characterizing the

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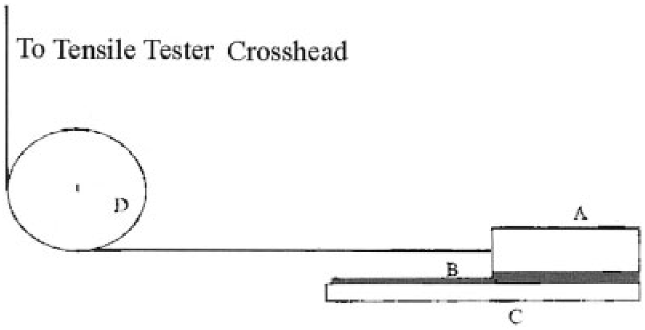

Figure 1 Schematic of the sliding friction apparatus: (A) the PMMA sled, (B) the fabric, (C) the aluminum platform, and (D) the frictionless pulley.

frictional properties with K is not practical, and this has led to the development of a refined friction factor (R).[2] R has been used to characterize the frictional properties of enzyme-treated fabrics. The enzyme treatment of fabrics etches the surfaces of fabrics, enhancing their smoothness. The novel friction factor R, obtained with the sliding friction method, is an objective measure for characterizing the enhancement in the smoothness of fabrics after enzyme treatments. The lower R is, the greater the smoothness is of the fabric, and vice versa.[2] However, the article did not investigate the effect of the speed of testing on the fabric frictional properties and its effect on R. In another study, R was used to characterize the frictional properties of needle-punched nonwoven fabrics. This novel friction factor was able to reflect subtle changes in the surface properties of needle-punched nonwovens.[7,21,22] In this article, we examine the relationship between the speed of testing and R.

DERIVATION OF THE NEW FRICTION CONSTANT

The coefficient of friction (μ) is not a logical measure for quantifying the frictional properties of polymeric and textile materials. The friction force/normal load relationship is not a simple linear relationship.[3,4] It can be conveniently represented as follows:

$$F/A = C(N/A)^n \quad (1)$$

where F is the friction force (N), N is the normal load (N), A is the apparent area (m^2), and C is the friction parameter (Pa^{1-n}). Solving eq. (1) results in the values of C and n. Experimental data for the static and dynamic frictional forces were obtained from a sliding friction tester, as shown in Figure 1. Frictional forces were obtained at different applied normal loads and were used in eq. (1). C and n were used to obtain the composite friction factor R (Pa^{1-n}):

$$C/n = R \quad (2)$$

R has been used to examine the effect of sliding frictional speeds on the frictional properties of a woven cotton fabric. This factor also enables us to understand the influence of different applied normal loads.

EXPERIMENTAL

As the objective of the study was to examine the effects of sliding speeds on the frictional properties of textile materials, only one fabric was used as the testing material. However, at each speed, frictional forces were evaluated at six different loads. The details of the fabric used are given in Table I.

Friction measurements

A sliding friction apparatus, shown in Figure 1, was used to measure the frictional forces over a range of applied normal loads. The sliding friction apparatus was combined with a constant-rate-of-extension tensile tester. The sliding friction apparatus basically consisted of an aluminum platform and a sled, which consisted of a poly(methyl methacrylate) (PMMA) plate (10 mm thick), with an apparent contact area of 20 cm^2, mounted on a wooden block. The maximum capacity of the load cell of the tensile tester was 25 kgf. One end of the sled was attached to the crosshead of the tensile tester by means of a nylon string through a frictionless pulley (D), as shown in Figure 1. Friction measurements were conducted at six different applied normal loads. The minimum load was 39.58 g, and the maximum load was 89.58 g. The load was increased in steps of 10 g. A rectangular piece of fabric was attached to the horizontal surface of the aluminum platform with a strip of double-sided adhesive tape. Special care was taken to ensure that no wrinkled samples were used, and when a sample was attached to the tape, no extra pressure was applied. The sled, with the PMMA surface in direct contact with the fabric, was pulled across the sample, and the frictional data were recorded. The study was conducted at five different velocities: 250, 400, 600, 750, and 1000 mm/min. The sled was always drawn across the weft (or filling)

TABLE I
Details of the Fabric Used

Type	Plain woven fabric
Ends	38.58/cm (98/in.)
Picks	31.89/cm (81/in.)
Warp size	15.42 tex (38.3 Ne)
Weft size	15.58 tex (37.9 Ne)
Weave	Plain
Weight	113.99 g/m^2 (3.32 oz/yd^2)

TABLE II
Experimental Results: Dynamic (D) and Static (S) friction

Sliding velocity (mm/min)		C (Pa^{1-n})	n	$R = C/n$ (Pa^{1-n})
250	S	0.815 (0.585)	0.867 (0.129)	1.044 (0.880)
	D	0.350 (0.112)	0.966 (0.040)	0.367 (0.135)
400	S	0.978 (0.284)	0.803 (0.060)	1.243 (0.433)
	D	0.547 (0.100)	0.896 (0.028)	0.614 (0.132)
600	S	1.750 (1.621)	0.595 (0.093)	2.845 (3.190)
	D	0.466 (0.060)	0.912 (0.021)	0.512 (0.078)
750	S	1.520 (1.030)	0.782 (0.191)	2.257 (1.764)
	D	0.332 (0.029)	0.947 (0.016)	0.351 (0.036)
1000	S	1.414 (1.028)	0.766 (0.134)	2.086 (1.840)
	D	0.328 (0.062)	0.944 (0.028)	0.349 (0.076)

The values within parentheses are standard deviations.

direction of the sample. Each test consisted of running the sled across the fabric with each of the six applied normal loads. In other words, each test consisted of six experiments corresponding to each applied normal load for a specified velocity.

Data collection and friction calculations

Both static and dynamic frictional resistances were measured for each run of a normal load at each sliding velocity. Built-in software in the tensile tester enabled automatic data recording and the calculation of the static and dynamic friction force values. A Matlab program was written to solve eqs. (1) and (2) and to obtain the friction parameter values, which are given in Table II.

RESULTS AND DISCUSSION

The goal of this study was to determine the influence of testing sliding speeds on C, n, and R. As R is the composite friction factor that compounds the effects of the two friction indices, C and n, we thought it appropriate to investigate the effects of sliding speeds on R values. In addition, we investigated the adequacy of the power-law relationship to represent the relationship between the friction force and the normal load. As shown by Figure 2, the relationship between the friction force and the normal load can be conveniently represented by the power-law relationship represented in eq. (1). Furthermore, on the basis of the residual values between the calculated and experimental values, it is evident that the power relationship is the best fit. Figure 3 shows the effects of the sliding speeds on the friction values. As the speed of sliding increases, the sliding friction increases up to a certain speed level. There is a rapid increase in the sliding friction values with an increase in speed from 250 to 600 mm/min, and then the effect is flattened. However, in the case of dynamic friction, the speed of sliding seems to have no significant effect.

Static friction is the initial friction offered to the smooth motion of the sled on the fabric. With an increase in the sliding speeds, the initial resistance to the movement is overcome with great momentum because of the shearing of the contact points resulting in enhanced friction. This may be the cause of the enhanced friction at sliding speeds of 250–600 mm/min. At lower sliding speeds, such as 250–600 mm/min, the time of contact between the fabric and the sliding friction sled is greater, resulting in more adhesion contact between the two surfaces. At lower sliding speeds, because of the greater adhesion, more force is required to overcome the adhesion, and this results in higher shearing at the contact points. The increased adhesion and the resultant shearing force result in a greater amount of friction. However, in the case of dynamic friction, which is the average of progressive resistances after static resistance, shearing forces do not rise with the speed, and this results in very minimal changes in the friction values. However, with a further increase in the speed beyond 600 mm/min, there seems to be no significant change in the static friction. After certain levels of sliding speeds, the contact time between the sled and the fabric significantly decreases, and this results in lower shearing forces at very high speeds, which result in marginal frictional variations. Changes in the frictional force values at different sliding speeds are clearly reflected in the friction factor values, C and R, as given in Table II. The results also show that C and R follow a similar trend with respect to the sliding speed changes. This result clearly indicates that R is a good quantitative factor for characterizing the frictional properties. There seems to be no significant change in the n values with the changes in the sliding speeds. n characterizes the nature of the material, and so it is not influenced by the sliding speeds. The results obtained in this study clearly show that R is quite adequate in quantifying the frictional properties of the polymeric textiles.

CONCLUSIONS

The frictional properties of a cotton woven fabric at different sliding speeds has been objectively characterized with a novel composite friction factor. The composite friction factor reflects the changes due to sliding speeds. The static friction increases steadily with an increase in the sliding speeds, but there is no significant effect on the dynamic friction values. The results also show that there is no significant effect on the friction index values due to the changes in the sliding speeds. In summary, the novel composite friction factor is a useful measure for characterizing the frictional properties of polymeric textiles.

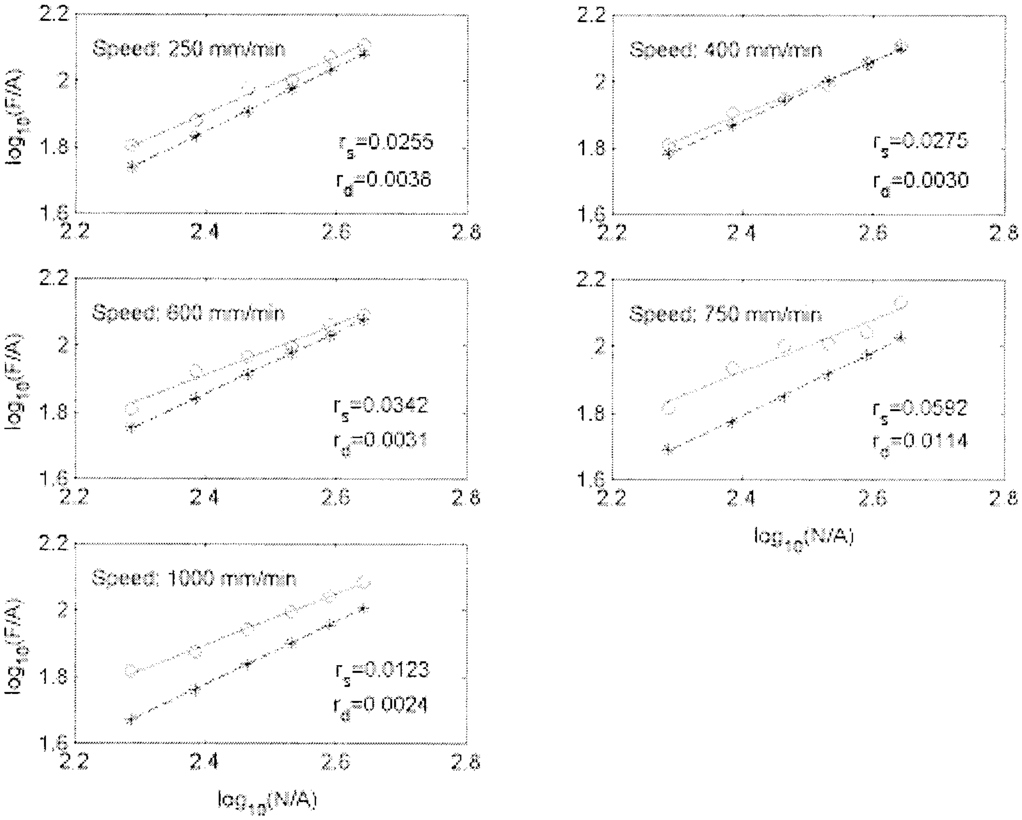

Figure 2 Log–log relationship between the normal load and frictional force: (○) static experimental, (—) static computed, (∗) dynamic experimental, and (- - -) dynamic computed. r_s and r_d denote the residual errors between the experimental and computed values, respectively.

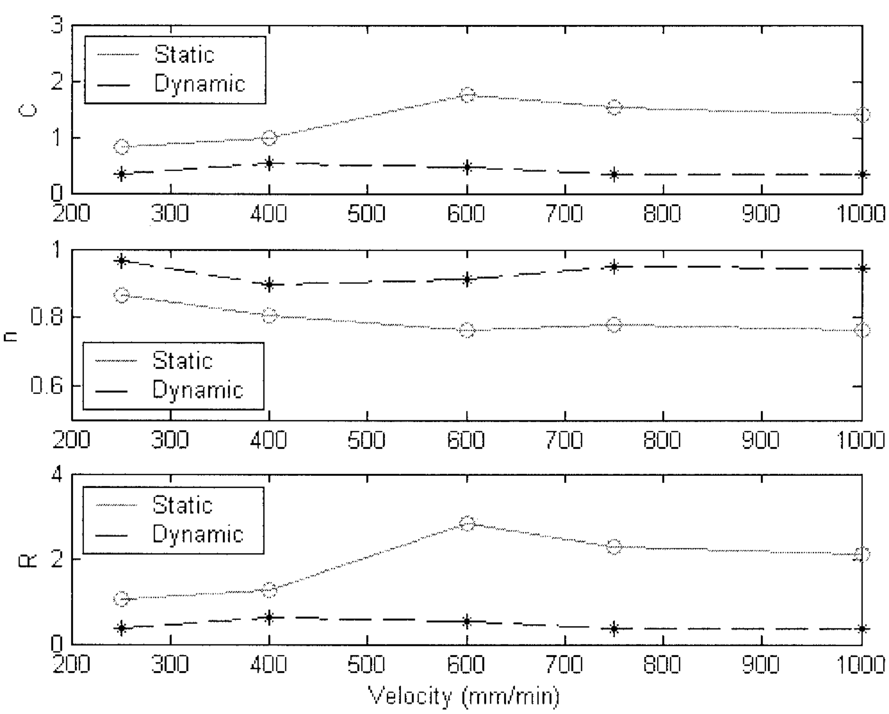

Figure 3 Relationship between the friction indices and the sliding velocity.

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