Experimental Study of the Frictional Properties of Friction Spun Yarns

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ABSTRACT: This article reports the results from a study conducted to characterize the frictional properties of friction spun yarns. The aim of the study was to obtain data on the surface mechanical properties of a variety of friction spun yarns. The study was essential as the surface mechanical properties influence the fabric formation, bonding strength, and high-performance properties of yarns. The yarns used in the study were made from different fibers and were spun at different speeds. The capstan method was used to obtain the friction force values between the yarns and a glass cylindrical rod. The experiment was conducted at different tensions. The results indicate that the friction of friction spun yarns are influenced by different factors such as the type of fiber and tensions applied. The results obtained help to understand the surface mechanical properties of high-performance yarns and their influence on the performance characteristics of friction spun yarns. © 2003 Wiley Periodicals, Inc. J Appl Polym Sci 88: 2450–2454, 2003

Key words: fibers; polyamides; polyesters; poly(propylene) (PP); surfaces

INTRODUCTION

The final quality of textile materials depends on the surface mechanical properties of fibers, yarns, and fabrics. With the advent of modern spinning systems, frictional properties of fiber assemblies have gained technical importance because of the role played by interfiber friction. In particular, the frictional properties of friction spun yarns are important because of the way the yarns are formed due to the friction between perforated drums rotating in the same direction. According to Gupta[1] and Zurek and Frydrych,[2] the common form of characterizing the frictional properties of yarns and filaments is the coefficient of friction, μ. The coefficient of friction determines the surface properties, the yarn and the fabric strength, etc.[3] A study conducted by Gupta and El Mogahzy[4] reported that the coefficient of friction is dependent on a number of parameters such as the normal force, the area of contact, speed of testing, and characteristics of the materials. This article reports the results from a study of the frictional properties of a set of friction spun yarns. The aim of the study was to understand the friction force/normal load relationship in high-performance and unconventional yarns such as friction spun yarns. In addition, the study also endeavored to understand the influence of the type of sheath fiber, the core element of the friction yarns, on the frictional properties. Such a study is of practical importance as it determines the performance characteristics of friction yarns in high-tech applications such as reinforcement material in body armor and composites.

EXPERIMENTAL

A set of different friction spun yarns used in the study were donated by Fehrer, AG (Linz, Austria). Details of the yarns used in the study are given in Table I. Friction spinning is a patented method of forming yarns due to the friction between rotating drums rotating in the same direction. Figure 1 shows the formation of friction spun yarns where fibers are twisted due to the friction between two perforated drums. The yarns used in this study were spun using the friction-spinning principle. This technology is developing at a rapid phase.[9] The yarns have a sheath and core structure due to the method of manufacturing as delineated in Figure 1.

FRICTION MEASUREMENTS

Frictional measurements of yarns were carried out using the experimental setup based on the capstan principle.[5] As shown in Figure 2, the yarn passes around the cylindrical glass rod that serves as the capstan. The glass rod is 1.5 cm in diameter and 20.5 cm in length. The yarn passes one full circle around the glass rod and the angle of the wrap is 6.283 rad.

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TABLE I
Friction Spun-Yarn Details

Sample ID	Details	Speed of spinning (m/min)	Friction-spinning type
1	Kevlar (1.7 dtex, 40mm) + filament glass 360 tex	150	DREF 3
2	PES (1.7 dtex, 38mm) + CU wire 0.25 mm ϕ	100	DREF 3
3	PES (1.7 dtex, 38mm) + CU wire 0.25 mm ϕ	150	DREF 3
4	Core Kevlar + sheath: viscose	150	DREF 3
5	Cotton carded + FIL.PES (275 dtex)	200	DREF 3
6	PA 6.0 + MONOFIL (0.5 mm ϕ)	100	DREF 3
7	Kevlar (4.7 dtex, 40 mm) + FIL.glass (68 tex)	150	DREF 2000
8	Cotton waste + FIL.PES (167 dtex)	240	DREF 2000
9	PP (2.8 dtex, 60 mm) + TAPE PP (440 dtex)	170	DREF 2000
10	PP (3.3 dtex, 38 mm)	180	DREF 2000
11	SYNTHETIK waste + FIL.PES (167 dtex)	200	DREF 2000
12	Cotton waste + FIL.PES (167 dtex)	180	DREF 2000

PES: polyester; PA: polyamide; PP: polypropylene; CU: copper.

One end of the yarn is attached to the load cell of the tensile tester and the other end is freely hung and is attached to a hook on which the loads are placed. Four different weights were applied to the yarns. The weights used were 10.5, 30.5, 50.5, and 70.5 g. The yarn withdrawal tension values (T_2) were calculated at different applied tensions (T_1) using eq. (1):

$$(T_2/T_1) = e^{\mu\theta} \tag{1}$$

The dynamic coefficient of friction at different applied tension levels is plotted in Figure 3.

Stick–slip trace of friction spun yarns

The typical stick–slip friction trace for a friction spun yarn at different normal loads is shown in Figure 4. As the applied tension increases, the yarns extend, resulting in a more straightened circular yarn. In addition, the applied tension in yarns results in a better arrangement of wrapper fibers in the yarn. This would result in a smoother surface in yarns, flattening the wrapper fibers, which results in reduction in friction at higher applied tensions as shown in Figure 3. Better wrapping of the wrapper fibers results in a lesser number of fibers protruding from the surface of the yarns. As the number of protruding fibers is reduced, there is less resistance to the smooth motion of yarns over the cylindrical glass rod, resulting in lower friction force. Furthermore, as the passage time of yarns around the capstan increases, frictional forces increase. This effect is more evident at the higher loads used in the study. This result can be attributed to enhanced contact between the cylindrical rod and the yarns at higher applied tensions. A prolonged duration of loading in yarns results in increase in the

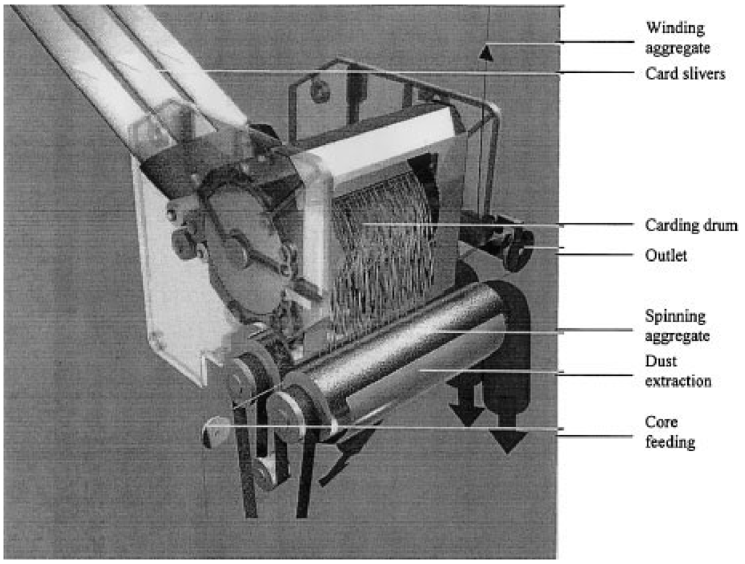


Figure 1 Operating principle of Dref 2000 friction spinning. (Source: Fehrer, AG, Linz, Austria.)

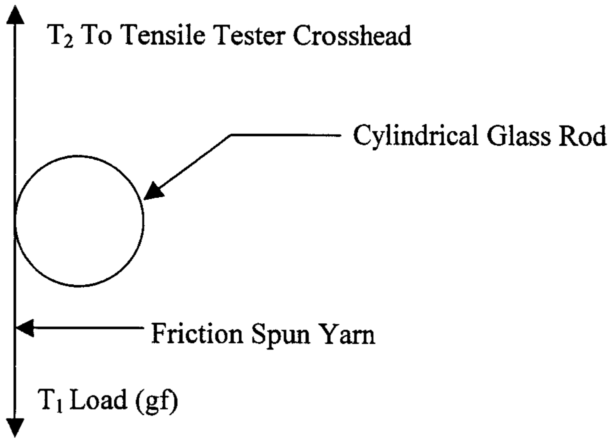


Figure 2 Experimental setup for friction force measurement.

contact between the yarns and the glass rod, resulting in more friction. This effect is more pronounced at higher tension levels due to the cumulative influence of the time of abrasion and tension levels.

RESULTS

The dynamic coefficients of friction (μ) for different friction spun yarns at different applied tensions (T_1) are given in Table II. Three repetitions were undertaken at each applied tension level for different samples used in this study

DISCUSSION

Effect of applied tension on dynamic coefficient of friction

As the applied tension increases, the tension in yarns increases and, hence, the true area of contact between the glass rod and the yarn increases. However, the friction force does not increase proportionally with the increase in applied tension. In the case of polymeric materials such as those used in this study, the friction force–normal load relationship is not linear. Ramkumar recently highlighted the deviations from Amonton's law of friction in the case of polymeric textile materials.[5–8] A sliding friction apparatus was fabricated to characterize the frictional characteristics of different textile substrates such as cotton-knitted fabrics, enzyme-treated fabrics, and nonwoven substrates.[6–8] The results from a recent study have shown that the power-law relationship as given in eq. (2) can be used to represent the relationship between friction forces and applied loads[6]:

$$F = CN^n \text{ for } (n < 1) \qquad (2)$$

where F is the friction force (gs); N, the normal applied load (gs); and C and n, the friction parameter and friction/material index, respectively. The coefficient of friction μ can be deduced from eq. (2) and is given by

$$\mu = F/N = CN^{n-1} \text{ for } n < 1 \qquad (3)$$

It is evident from eq. (3) that, as the applied load increases, the coefficient of friction μ decreases. With increase in the applied tensions, the coefficient of friction of friction spun yarns decreases. This trend is evident in almost all the yarns investigated in this study (Fig. 3).

Effect of speed of spinning and filament characteristics

In comparing samples 2 and 3 and samples 8 and 12, it is clear that the speed of spinning plays a role on the frictional properties. As the speed of spinning increases, the tension in the yarn increases. Due to the nature of the friction spinning process and the method of yarn withdrawal, the tension level in the yarn increases.

As described in the section Stick–Slip Trace of Friction Spun Yarns, higher tension in yarns results in well-aligned fibers in the yarn structure. Also, the wrapper fibers become well integrated within the structure, resulting in smoother surfaces. The reduction in friction at higher speeds can be attributed to smoother yarn surfaces due to a well-integrated yarn structure. As shown in Figure 5, this effect is evident at tension levels higher than 10.5 g. From limited experiments undertaken in this study, it seems that the characteristics of the core yarns have an effect on the frictional properties. It is possible to compare this effect using yarns 1 and 7 in this study as these yarns are produced using the friction spinning principle al-

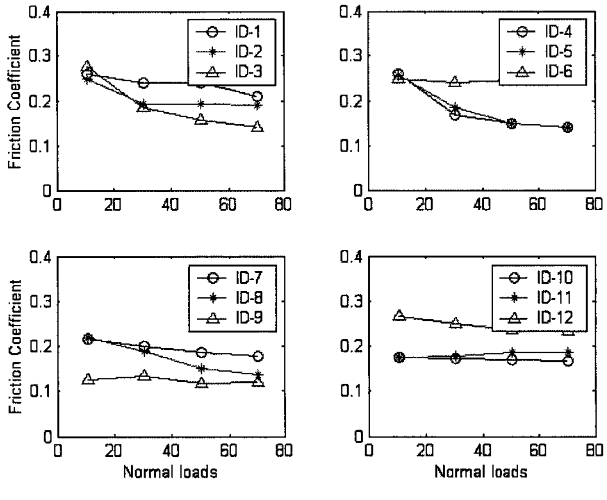
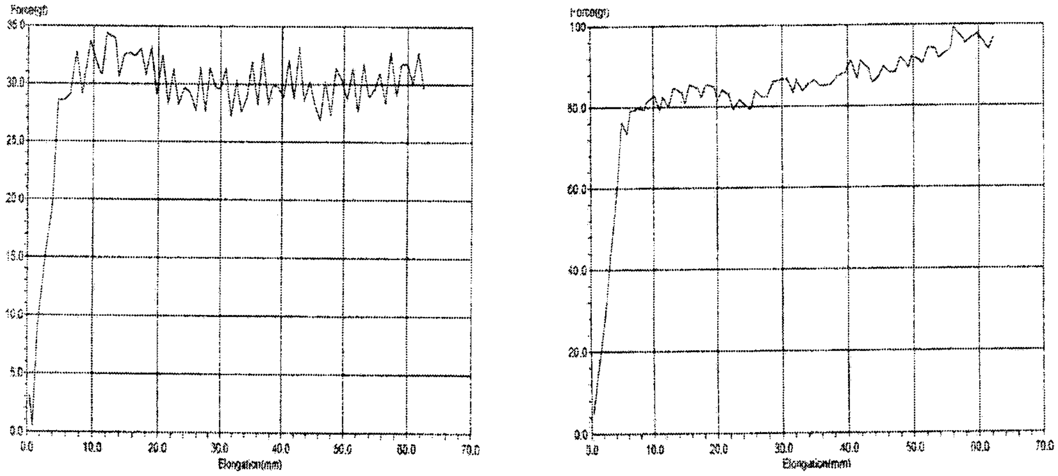
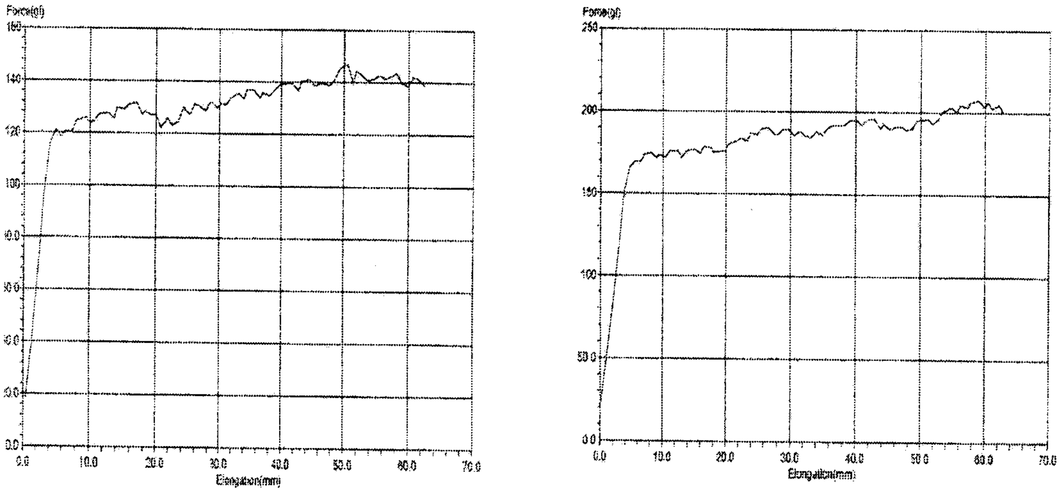


Figure 3 Coefficient of friction (μ) versus applied tension (gf).



Normal Load = 10.5 gms. **Normal Load = 30.5 gms.**



Normal Load = 50.5 gms. **Normal Load = 70.5 gms.**

Figure 4 Frictional trace at different applied tensions.

TABLE II
Dynamic Coefficient of Friction for Different Samples at Different Applied Tensions

	Dynamic coefficient of friction at different applied tensions T_1			
Sample ID	T_{10} (10.5 g)	T_{11} (30.5 g)	T_{12} (50.5 g)	T_{13} (70.5 g)
1	0.259 (0.014)	0.240 (0.008)	0.240 (0.014)	0.210 (0.007)
2	0.248 (0.004)	0.193 (0.008)	0.192 (0.014)	0.191 (0.007)
3	0.277 (0.037)	0.185 (0.04)	0.157 (0.027)	0.141 (0.019)
4	0.260 (0.022)	0.168 (0.007)	0.148 (0.003)	0.141 (0.011)
5	0.257 (0.012)	0.186 (0.037)	0.150 (0.004)	0.140 (0.003)
6	0.248 (0.110)	0.239 (0.021)	0.247 (0.024)	0.243 (0.011)
7	0.216 (0.010)	0.201 (0.008)	0.185 (0.006)	0.177 (0.006)
8	0.219 (0.010)	0.188 (0.023)	0.151 (0.019)	0.136 (0.005)
9	0.126 (0.008)	0.133 (0.007)	0.118 (0.003)	0.121 (0.008)
10	0.174 (0.008)	0.172 (0.017)	0.170 (0.013)	0.166 (0.014)
11	0.176 (0.006)	0.179 (0)	0.186 (0.008)	0.186 (0.003)
12	0.265 (0.013)	0.249 (0.021)	0.237 (0.014)	0.234 (0.015)

The values indicated within the parentheses correspond to the standard deviation values.

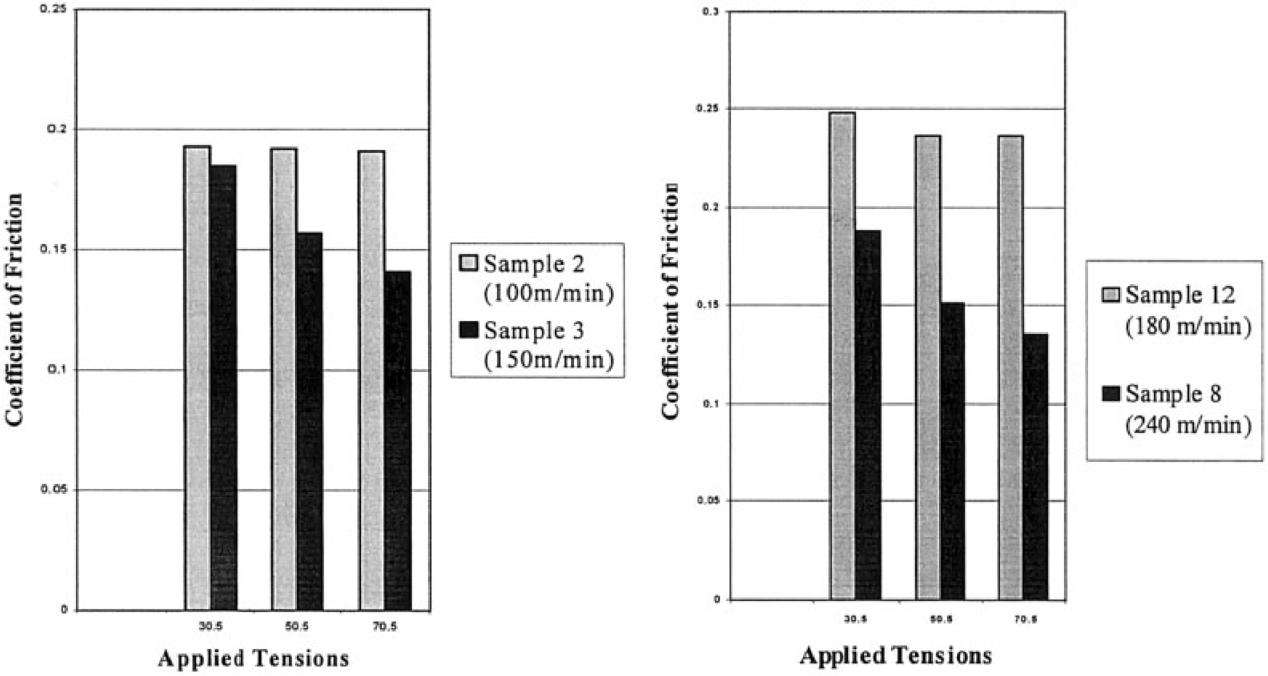


Figure 5 Speed of spinning on friction values.

though the spinning machine versions are different. Yarn 1 has a thicker core element compared to yarn 7. The results show that the coefficient of friction values are lower for yarn 7, which has a thinner core element. The decrease in frictional values for thinner core yarns is evident at all applied tension levels. It should be noted that, due to the unavailability of samples with different core elements, it was not possible to undertake a detailed study for comparing the effect of core element characteristics on the frictional properties. However, results obtained from this limited study are an indicator of the influence of core-element characteristics on the coefficient of friction values. It is the authors' view that an elaborative study is needed to have conclusive results.

CONCLUSIONS

This article has reported the results from a brief study of the frictional properties of friction spun yarns. Friction occupies a prominent role in the strength contribution of fiber assemblies; the exercise was carried out to obtain frictional data on a set of high-performance yarns. The experimental setup used in this study was found to be suitable to measure the frictional properties of a set of high-performance friction spun yarns at different tension levels. Results from the limited study have shown that the frictional values are influenced by the applied tension on the yarns. Other parameters such as the speed of spinning and the characteristics of the core elements seem to influence the frictional properties. However, due to sample limitations, it has not been possible to conclusively evidence the influence of these aforementioned parameters on the frictional properties. A detailed study has to be undertaken to investigate the influence of additional parameters such as the speed of spinning, type and the nature of core elements, and the finishes applied to the yarns.

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