A Study on Dynamic Friction of Different Spun Yarns

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Received 13 September 2007; accepted 7 November 2007
DOI 10.1002/app.27633
Published online 4 March 2008 in Wiley InterScience (www.interscience.wiley.com).

ABSTRACT: This article presents the results from a study of yarn-to-yarn (YY) and yarn-to-metal (YM) frictions conducted on ring, rotor, air-jet, and open-end friction (OE friction) spun yarns at different relative speeds and input tensions. The results indicate that the behavior of frictions for YY is different than that of YM. In case of YY friction, OE friction yarn shows maximum friction followed by rotor, air-jet, and ring spun yarns; however, a reverse order is noticed for YM friction. The relative speed and input tension have significant influence on the frictional behavior of spun yarns. © 2008 Wiley Periodicals, Inc. J Appl Polym Sci 108: 3233–3238, 2008

Key words: fiber; structure; surfaces; tension

INTRODUCTION

Both yarn-to-yarn (YY) and yarn-to-metal (YM) frictions play an imperative role in textile processing. Yarns experience friction either between themselves or against metallic surfaces before being processed into fabric in weaving and knitting machineries. High YY and YM frictions may shoot up the end breakage rate during weaving. An insight into the nature of YY and YM friction may help to improve the processing performance of yarns.[1] YY friction plays a major role in the fabric assistance and consolidates the fabric tensile properties.[2] Yarn friction eventually affects the fabric handle to a large extent. With the advent of new spinning technologies like rotor and friction spinning, YM friction has boosted technical importance. During the yarn formation in rotor and friction spinning systems, yarns encounter friction against the metallic surfaces of rotor disc and the rotating perforated drums, respectively. The frictional behavior of the staple yarns is strongly governed by the nature of their surfaces. The spun yarns produced by various spinning technologies differ significantly from each other in their surface characters and this difference is likely to be reverberated in their frictional behavior. Yarn friction is reported to be dependent on relative speed and input tension.[3–5] Very limited information is available to date on the study of frictional behavior of different spun yarns.[6–8] Therefore, the present work is endeavored to explore the behavior of dynamic friction of yarns spun on various spinning technologies.

GENERAL MECHANISM OF FRICTION

Friction, in general, is the force that opposes relative motion between two surfaces in contact. It is the resistance encountered when two bodies in contact are allowed to slide. In 1699, Amontons proposed classical law of friction, which states that the frictional force is proportional to the applied normal force and it is independent of the area of contact between the two sliding objects. This law explains the frictional behavior successfully for metals that deforms plastically, but fails to do so in case of objects, such as textile materials, which exhibit visco-elastic deformation. The desirable mechanism to explain the frictional behavior may be read as follows.[9]

The surfaces of most of the materials, even a highly polished one show micro-asperities of different height equal to several hundred molecular dimensions while viewing under a powerful microscope. When two surfaces come in contact, only the apex points of the few asperities of both the surfaces touch each other and the real contact area is very much lesser as compared to the apparent area of contact. When a normal load is applied, the pressure at the actual contact points becomes so extreme that the tips of the asperities crumble down. Accordingly, the area of true contact increases with a corresponding reduction in pressure. The nature of this defor-

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Journal of Applied Polymer Science, Vol. 108, 3233–3238 (2008)
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mation is dependent on the mechanical properties of the materials. In case of metals, plastic flow occurs and the flow continues until the pressure at the points of contact reduces to the value of yield pressure and eventually real area in contact becomes adequate to support the given normal load without further deformation. The normal load is linearly proportional to the true area in contact. Therefore, the true area in contact, which remains constant at a given normal load, is independent of number of contact points as well as apparent area of contact for metals. Conversely, for textile materials, which deform visco-elastically, the relationship between the normal load and real area in contact is nonlinear. It thus follows that the real area in contact depends on the number of contact points and apparent area of contact at a given normal load for visco-elastic materials.[10]

For both metals and textile materials, the pressure at the real contact points will be very intense with a corresponding rise in temperature. As a result of that many contact points do cold-weld together to form a junction. These welds produce static friction while an applied load attempts to slide the surfaces relative to each other. If the applied force is great enough to pull one surface across the other, there is first tearing of welds and then continuous reforming and tearing apart of welds as movement occurs and new contacts are made.[11]

EXPERIMENTAL

Viscose fibers of 1.5 denier and 44 mm length were spun to produce 30 tex yarns on ring, rotor, air-jet, and friction spinning systems. The spinning parameters employed for each yarn were those that are considered appropriate by commercial spinners, based on their experience with each of the spinning systems. The twist multipliers (TM in cotton system) for ring and rotor spun yarns were 3.75 and 4.2, respectively. A Lakshmi LG 5/1 ring frame and Rieter M 2/1 machines were used to produce ring and rotor yarns, respectively. The air-jet and open-end (OE) friction yarns were made on MJS-802 H and Dref-III friction spinner, respectively.

YY and YM friction in dynamic condition was measured using a friction measuring apparatus fabricated in the laboratory.[6] A schematic diagram of the main operational area of the apparatus is depicted in Figure 1. The yarn from the supply package (1) passes through the thread guide (2) and then over an inlet rotatable guide roller (3). A tension compensator (4) was placed to control the input tension of yarn amid the thread guide (2) and inlet guide roller (3). After that, the yarn passes over a metallic pulley (5) and subsequently, the delivery and feed ends of the yarns are given two turns (in case of YY friction) before it is passed over an outlet rotatable guide roller (6) and a delivery roller (7). To represent rubbing or frictional contact of yarns with each other during weaving, yarns are given two turns by passing one yarn over another.

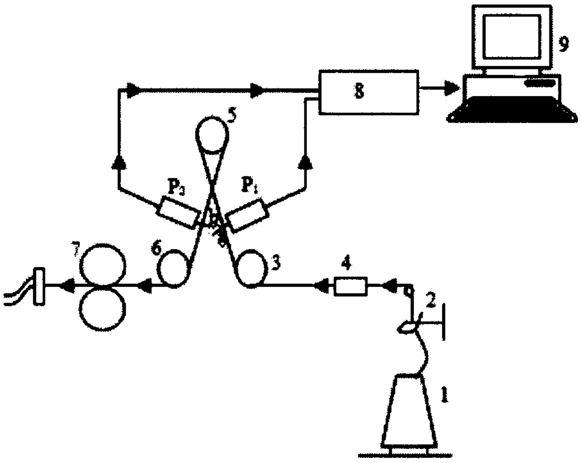

Figure 1 A schematic diagram of the main operational area of the apparatus to measure the frictional characteristics.

In case of the measurement of YY friction, the metallic pulley (5) was selected as rotatable type and therefore the friction between yarn and metallic pulley may well be neglected.

But, to measure the friction between yarn and metal a fixed type of metallic pulley was employed in place of the rotatable type (5). The position of guide rollers (3) and (6) were adjusted in such a way that the yarn passage becomes parallel during its entry and exit in the measuring zone after making a half turn to the stationary metallic pulley.

The measuring heads of tension probes (P_1 and P_2) were positioned at places a and b as illustrated in Figure 1. When a yarn passes over the measuring head of tension probe, the pressure applied by the yarn causes a change in the capacitance, and the change being proportional to the applied tension. Rothschild electronic tensiometer (8) detects the changes in capacity from P_1 and P_2 and translates them electronically into a meter reading, which indicates the input and output tensions (T_1 and T_2 cN, respectively). The tensiometer has an interface with a computer (9) and a software ''Rothschild ETR 2000'' plots the input and output tensions. The response time of the measuring system was set at 0.1 s. Each sample was tested for duration of 5 min.

Yarns were tested for friction at different levels of input tensions, viz., 2, 4, 6, 8, and 10 cN. The input tensions are taken in the ranges from 2 to 10 cN after carrying out several trials, considering the yarn linear density. To simulate the frictional behavior of YY

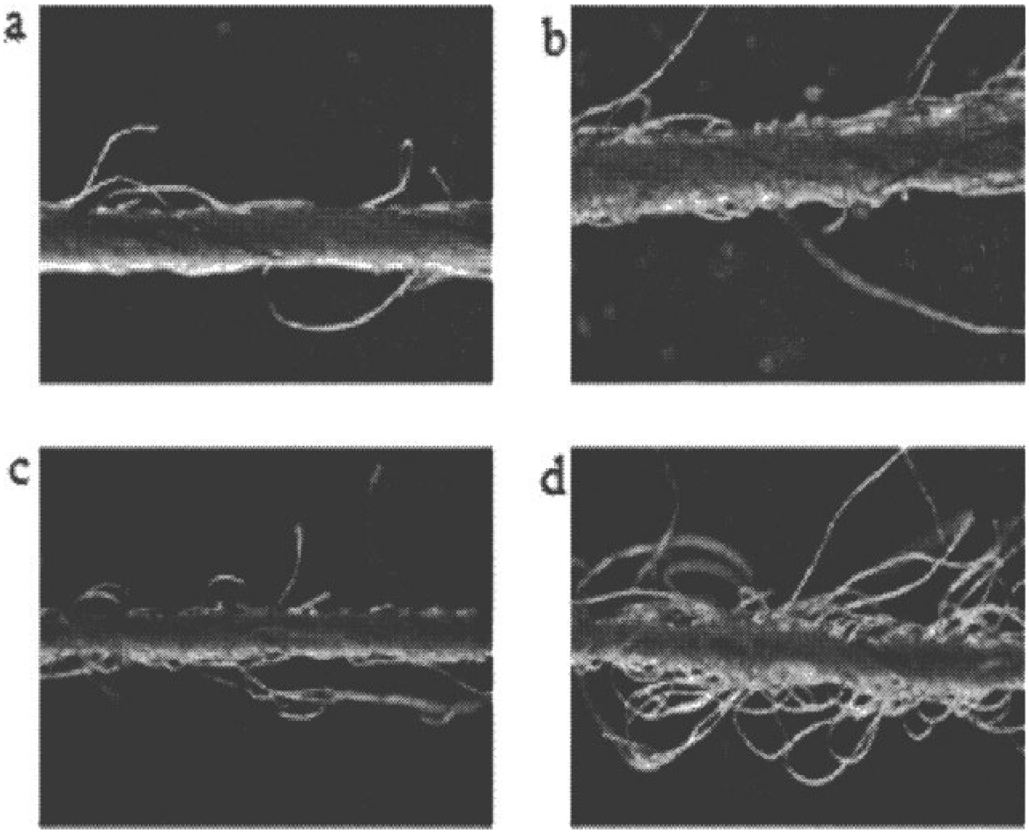

Figure 2 Images of different spun yarns (a) ring, (b) rotor, (c) air-jet, and (d) OE friction.

and YM with the actual processing of yarns at various stages between spinning to weaving, the speeds of the delivery roller (7) were chosen at both lower range (0.5 and 15 m/min) and higher range (100 and 200 m/min). The ratio between the output and input tensions (T_2/T_1), which is proportional to the coefficient of friction, as well as the frictional force, which is the difference between out put and input tensions (T_2-T_1) were estimated.

To study the characteristics of yarn surfaces, the yarns spun on different spinning systems were observed under a Lieca digital microscope with a magnification of 40× and the images of the yarn surfaces were recorded in the computer.

RESULTS AND DISCUSSION

Surface character of various spun yarns

The nature of the yarn surfaces that are mutually in contact plays a key role to govern the frictional behavior of yarns. It is an established fact that the surface characters of various spun yarns are different. Ring spun yarn is usually characterized by an assembly of ideal cylindrical helix of well oriented fibers with a hairy surface [Fig. 2(a)]. The rotor spun yarn shows a bipartite or two-zone structure comprising a core of fibers that are aligned with the helix of the inserted twist and form the bulk of the yarn and then an outer zone of wrapper fibers, which occurs irregularly along the core length [Fig. 2(b)]. The air-jet spun yarn consists of a majority of fibers in an almost untwisted state in the core and a surface layer of fibers wrapped around the core, which, similar to rotor yarn, occurs irregularly along the core length [Fig. 2(c)]. Rotor and air-jet spun yarns yield higher surface roughness than that of ring spun yarn because of the presence of wrapper fibers. The OE friction spun yarn is characterized by its poorer fiber orientation, inferior packing, and a very rough surface having many looped, buckled, and loose hairy fibers [Fig. 2(d)].

YY friction

The values of YY friction both in terms of tension ratio and frictional force at different levels of input tension and relative speeds are displayed in Table I. Figure 3 presents the influence of relative speed on tension ratio at a constant input tension of 6 cN. The effect of input tension on YY tension ratio at a constant relative speed of 100 m/min is depicted in Figure 4. It is clearly demonstrated that the OE friction yarn shows maximum friction followed by rotor, air-jet, and ring spun yarns. This may be ascribed to the

TABLE I
Values of YY Friction

Yarn Sample	Input Tension (cN)	Relative Speed (m/min) 0.5		15		100		200	
		Friction Force (cN)	Tension Ratio	Friction Force (cN)	Tension Ratio	Friction Force (cN)	Tension Ratio	Friction Force (cN)	Tension Ratio
Ring	2	6.66	4.33	5.46	3.73	6.44	4.22	7.38	4.69
	4	10.24	3.56	10.04	3.51	11.40	3.85	12.72	4.18
	6	13.86	3.31	13.08	3.18	15.66	3.61	18.06	4.01
	8	17.44	3.18	16.48	3.06	20.24	3.53	23.36	3.92
	10	21.00	3.10	19.40	2.94	23.20	3.32	28.70	3.87
Rotor	2	10.44	6.22	8.24	5.12	9.20	5.60	12.74	7.37
	4	17.72	5.43	14.92	4.73	15.8	4.95	18.72	5.68
	6	24.06	5.01	21.60	4.60	22.68	4.78	24.66	5.11
	8	30.32	4.79	28.24	4.53	29.52	4.69	31.44	4.93
	10	36.70	4.67	33.60	4.36	34.90	4.49	37.20	4.72
Air-jet	2	9.34	5.67	7.90	4.95	8.70	5.35	11.14	6.57
	4	16.72	5.18	14.08	4.52	14.76	4.69	17.96	5.49
	6	22.08	4.68	20.16	4.36	21.12	4.52	23.58	4.93
	8	27.44	4.43	25.52	4.19	27.04	4.38	29.60	4.70
	10	32.80	4.28	29.80	3.98	31.10	4.11	34.90	4.49
OE-friction	2	11.44	6.72	9.58	5.79	9.90	5.95	13.12	7.56
	4	19.48	5.87	16.40	5.10	18.52	5.63	19.92	5.98
	6	26.34	5.39	23.22	4.87	25.44	5.24	27.24	5.54
	8	32.48	5.06	30.08	4.76	32.72	5.09	34.08	5.26
	10	38.40	4.84	36.90	4.69	39.60	4.96	42.10	5.21

difference in the surface roughness corresponding to the various yarns. When the surface of a yarn slides over it's another surface, relatively rougher yarn yields more area of contact and thereby increases friction.

Furthermore, it may be noticed that as the relative speed increases both the values of frictional force and tension ratio initially diminish, and then rise. Invariably, the minimum value of yarn friction was observed at 15 m/min relative speed for all spun yarns. This may be attributed to the fundamental differences exist in the frictional behaviors of yarns in the three distinct zones viz., boundary, semi-boundary, and hydrodynamic. In the boundary and semi-boundary regions, which occur at lower speeds, friction tends to decrease with an increase in relative speed. But in the hydrodynamic region, which comes up relatively at higher speeds, the friction is an increasing function of the relative speed. The semi-boundary region, which comprises the minimum friction, passes through the speed of 15 m/min in this case.

It is also observed that the frictional forces increases but the tension ratio diminishes with increased input tension. This may be down to the fact that an increase in the input tension (T_1) leads

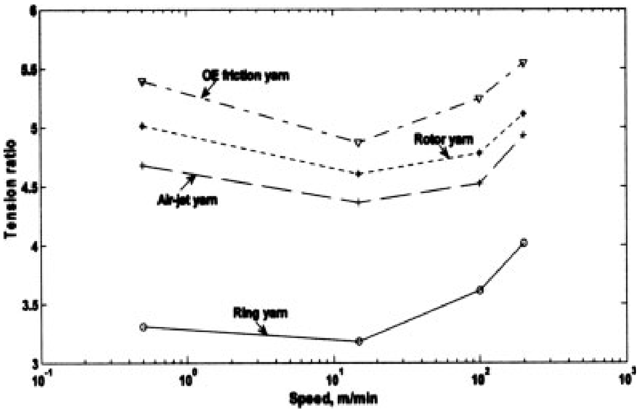

Figure 3 Influence of relative speed on YY tension ratio (at 6 cN input tension).

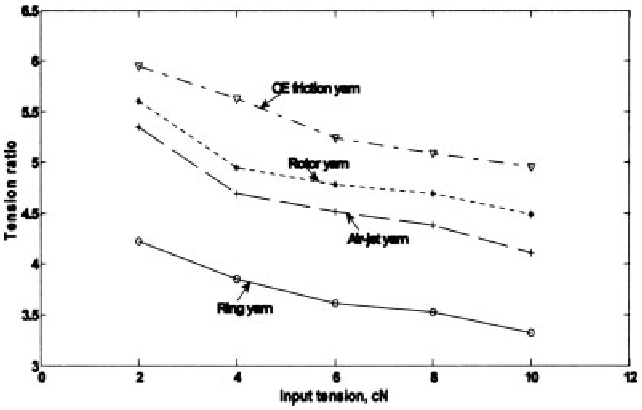

Figure 4 Influence of input tension on YY tension ratio (at 100 m/min speed).

TABLE II
Values of YM Friction

		Relative Speed (m/min)							
		0.5		15		100		200	
Yarn Sample	Input Tension (cN)	Friction Force (cN)	Tension Ratio	Friction Force (cN)	Tension Ratio	Friction Force (cN)	Tension Ratio	Friction Force (cN)	Tension Ratio
Ring	2	4.38	3.19	7.42	4.71	8.02	5.01	9.06	5.53
	4	8.12	3.03	13.52	4.38	15.84	4.96	16.96	5.24
	6	11.46	2.91	19.56	4.26	23.64	4.94	24.96	5.16
	8	14.8	2.85	25.68	4.21	31.44	4.93	32.40	5.05
	10	18.10	2.81	31.70	4.17	39.20	4.92	39.90	4.99
Rotor	2	3.76	2.88a	5.96	3.98	6.56	4.28	6.78	4.39
	4	6.76	2.69	11.32	3.83	12.24	4.06	13.24	4.31
	6	9.78	2.63	16.68	3.78	17.88	3.98	19.02	4.17
	8	12.80	2.60	22.00	3.75	23.52	3.94	24.72	4.09
	10	15.80	2.58	27.40	3.74	29.20	3.92	30.10	4.01
Air-jet	2	3.94	2.97	6.58	4.29	7.52	4.76	7.86	4.93
	4	7.36	2.84	12.60	4.15	14.48	4.62	15.16	4.79
	6	10.74	2.79	18.78	4.13	21.30	4.55	22.50	4.75
	8	14.16	2.77	24.72	4.09	28.16	4.52	29.60	4.70
	10	17.60	2.76	30.40	4.04	34.50	4.45	36.60	4.66
OE-friction	2	3.38	2.69	5.30	3.65	5.90	3.95	5.98	3.99
	4	5.96	2.49	10.44	3.61	11.20	3.80	11.48	3.87
	6	8.58	2.43	15.48	3.58	16.38	3.73	16.92	3.82
	8	11.12	2.39	20.24	3.53	21.12	3.64	22.32	3.79
	10	13.80	2.38	24.70	3.47	25.80	3.58	27.20	3.72

to higher normal force at the area of contact, therefore the frictional force (T_2-T_1) goes up. Nonetheless, since the frictional force is a nonlinearly increasing function of input tension, the tension ratio (T_2/T_1) reduces.

YM friction

The results of YM friction are depicted in Table II. Figures 5 and 6 present the influence of speed and input tension on tension ratio, respectively. The maximum and minimum frictions were observed for ring and OE friction yarns, respectively. It may be appreciated that the result of YM friction shows exactly opposite trend than that of YY friction. This may be substantiated on the basis of the fact that the morphology of yarn and metal surfaces are entirely different and essentially yarn surface is much rougher in comparison with the metal surface. Therefore, when the surface of a yarn slides over a smooth metal surface, comparatively smoother yarn produces more area of contact and consequently increases friction. In contrast to this, when both the surfaces are rough, the rougher the yarn the higher is the total area of contact as well as friction.

Moreover, it is noted that both the frictional force and tension ratio continually increase with increased relative speed between yarn and metal. This can be

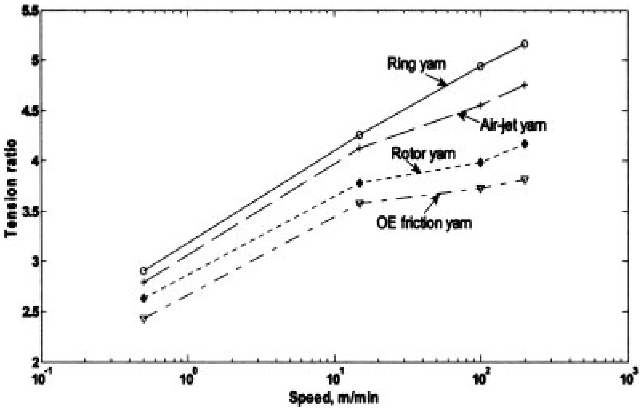

Figure 5 Influence of relative speed on YM tension ratio (at 6 cN input tension).

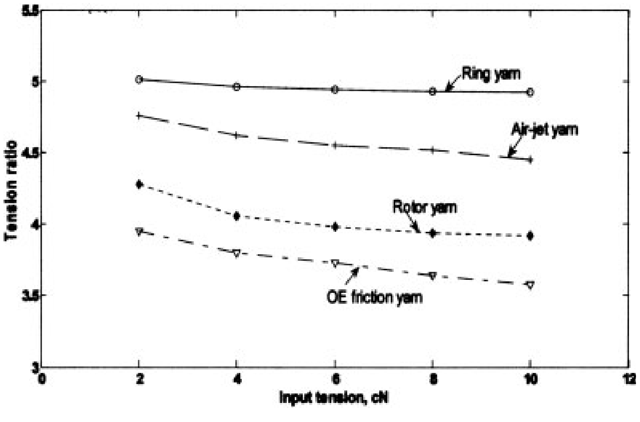

Figure 6 Influence of input tension on YM tension ratio (at 100 m/min speed).

advocated to the fact that in case of YM friction, perhaps the hydrodynamic region starts even at low speed (0.5 m/min) considered in this study, owing to the difference in the surface nature between yarn and metal, whereas, the hydrodynamic region occurs relatively at higher speed for YY friction.

However, the effect of the input tension on frictional force and tension ratio for YM friction shows an analogous result as observed for YY friction. This can be explained on similar lines of the reasoning as described for YY friction.

CONCLUSIONS

The surface character of yarns plays a substantial role to determine the dynamic friction. Relatively rougher yarn surface yields higher YY friction. On the contrary, the reverse trend was observed in case of YM friction. The relative speed and input tension have considerable influence on the frictional behavior of spun yarns. As the relative speed increases YM friction increases, however YY friction passes through a minimum with speed. For both YY and YM friction, the frictional forces increases but the tension ratio reduces with increased input tension.

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