Fibers and Polymers 2005, Vol.6, No.3, 259-262

Frictional and Tensile Properties of Conducting Polymer Coated Wool and Alpaca Fibers

Lijing Wang, Tong Lin, Xungai Wang, and Akif Kaynak*

School of Engineering and Technology, Deakin University Geelong, Victoria, 3217, Australia

(Received January 15, 2005; Revised March 23, 2005; Accepted April 6, 2005)

Abstract: Wool and alpaca fibers were coated with polypyrrole by vapor-phase polymerisation method. The changes in frictional and tensile properties of the single fibers upon coating with the conductive polymer are presented. Coating a thin layer of polypyrrole on the alpaca and wool fibers results in a significant reduction in the fiber coefficient of friction, as the conducting polymer layer smooths the protruding edges of the fiber scales. It also reduces the directional friction effect of the fibers. Depending on the type of fiber, the coating may slightly enhance the tensile properties of the coated fibers.

Keywords: Polypyrrole, Wool fiber, Vapor coating, Tensile properties, Coefficient of friction

Introduction

Electronic textiles are fabrics/garments that contain electronic circuits, optical fibers or sensors. Such functional textiles provide potential opportunities for boundless applications in electronic interfaces [1] and in the field of health care. It is highly likely that within 10 years, computer chips will be integrated into garments and wearable technology will become as common as mobile phones. One of the most practical techniques to make textiles electrically conductive is to apply conductive polymers onto the fabric surface. Conductive polymers have a comparable degradation lifetime to textile materials [2]. The coating is easily applied and does not have a significant effect on the fabric softness. Therefore, conductive polymer coated textiles are promising materials for wearable electronics.

Conducting polymers have a unique property of wide ranging modulation of their electrical conductivity. They can be synthesized to possess a conductivity value ranging from insulating to highly conductive, e.g., 10^2 S/cm, by incorporating specific concentrations of dopant counter-ions during polymerisation [3,4]. Applications of free-standing conducting polymer films are very limited as they tend to be brittle, insoluble and cannot be melted. However, by coating textile substrates with conductive polymers, their desirable electrical properties can be combined with the strength and flexibility of textiles to produce conductive fabrics with a wide range of electrical properties.

There have been some recent publications on conductive polypyrrole coated textiles [5-7]. In most reports, coating was achieved by chemical polymerization in the presence of a substrate, which was exposed to an oxidizing agent, monomer and a dopant simultaneously or sequentially with specified reactant concentrations. The reaction is initiated by the oxidation of monomer into radical cations, which combine to form dimers. Continuation of the process leads to formation of insoluble oligomers both in solution and on the surface of the substrate. For example, wool yarns can be directly coated with conductive polymers by using the in-situ polymerization method [8]. The conducting polypyrrole coated wool yarns exhibited higher stress/tenacity, higher breaking strain and lower initial modulus than uncoated yarns [8]. The preparation method for coating affects not only the conductivity, but also the physical and mechanical properties of the composite textiles. Little work has been reported on the evaluation of the variation of physical and mechanical properties of conductive textile fibers. In this paper, we examine the effects of conducting polypyrrole coating on the properties of animal fibers, in particular, the change of frictional and tensile properties of coated wool and alpaca fibers.

Polypyrrole has been used to form a conducting layer on the insulating surfaces such as polyester films and fabrics [9,10]. Coating can be done by either solution [11] or vapor phase deposition of conducting polymers on substrates. During the latter, monomers in the vapor state react with the oxidant, which is previously deposited on the substrate surface, to form a thin conducting polymer layer. The vapor-phase method results in a more uniform coating and is thought to produce a better bonding connection with the substrate than the solution polymerization method, which exposes the substrate to an oxidizing agent, monomer and dopant simultaneously. In this paper, vapor coating technology was used to prepare conductive fibers.

A feature of all animal fibers is the Directional Friction Effect (DFE). This suggests that the coefficient of friction against the scales is greater than the coefficient of friction along the scales. There will be no DFE if the coefficient of friction against the scales is the same as the coefficient of friction along the scales. Mathematically DFE is expressed by:

$$DFE(\%) = \frac{\mu_a - \mu_w}{\mu_a + \mu_w} \times 100 \quad (1)$$

Where, μ_a is the coefficient of friction against the direction

*Corresponding author: akaynak@deakin.edu.au

of scale and μ_w is the coefficient of friction along the direction of scale. The conducting polymer coating affects the surface morphology of animal fibers, hence changes the coefficient of friction and other fibre properties. In this paper, we examine the effect of polypyrrole layer on the coefficient of friction and DFE of wool and alpaca fibers.

Experimental

Fibers

Wool and alpaca fibers were used to examine the effects of conducting polymer coating on fiber frictional and tensile properties. Greasy lamb's wool, normal wool and alpaca fibers were sampled from sale lots and then scoured under identical conditions. The normal wool was a combination of samples from different micron lots. In this paper it is labelled as "Broad Wool". Two sub samples were taken from each sample. One of the sub samples is the control and the other is subjected to conducting polymer vapor coating.

Conducting Polymer Vapor Coating

5 gram samples of both wool and alpaca fibers were firstly impregnated with the oxidant, 200 *g/l* ferric chloride ($FeCl_3$), and then treated with pyrrole-saturated air for 45 minutes, resulting in a uniform, smooth and adherent coating of conducting polymer.

Resistivity Measurements

Electrical resistivity measurements were carried out on the coated fiber using a test rig with two rectangular copper electrodes (measuring 20 × 30 mm) separated by 2 cm. The rig was placed on the coated fiber sample with a pressing force of 10N. The resistance was recorded with a Fluke 83 III Multimeter.

Frictional and Tensile Test Procedures

Coated and uncoated fibers were conditioned in a standard atmosphere for more than 48 hours. Single fibers were then randomly sampled for coefficient of friction tests using an Y151 fiber coefficient of friction tester. The fiber frictional force was measured against an 8 mm metal rod. The fiber pretension was 100 mg and the testing speed was set at 30 rpm. Each tested fiber was further analysed by a Single Fiber Analyser (SIFAN), which first measures the diameter profile of a single fiber and then tensile properties of the fiber. Each fiber diameter profile was measured at an interval of approximately 6 μm along the fiber length, and its tensile properties were measured at a speed of 500 mm/min. The full fiber length was used for tensile testing, hence the gauge length varied. At least 20 single fibers were measured from each sample. All tests were conducted in the conditioned laboratory. Scanning Electron Microscopy (SEM) images of fibers were obtained using a LEO 1530 microscope.

Results and Discussion

General Information on Tested Fibers

As shown in Table 1, the tested single fibers display a wide range of lengths and diameters.

Electrical Conductivity

The resistance of conducting polymer coated fibers is approximately 2 kΩ, while that of uncoated fibers is too large to measure. This demonstrates that polymer deposition on the surface of the fibers has occurred and coating has rendered the fiber conductive.

Frictional Properties

Figure 1 shows that conducting polymer coating decreases the coefficient of static friction. Statistical significance test results in Table 2 show that the difference is significant as the *P* value, which is the probability that the two means of

Table 1. Lengths and diameters of tested single fibers

	Coating	Parameter	Alpaca	Lamb wool	Broad wool
Length	Uncoated	Mean (mm)	119.96	49.41	97.69
		CV_L (%)	24.80	24.88	47.17
		Min (mm)	56.38	32.90	52.43
		Max (mm)	140.61	62.39	144.81
	Coated	Mean (mm)	93.56	47.29	110.07
		CV_L (%)	22.51	15.53	12.54
		Min (mm)	41.66	32.05	81.95
		Max (mm)	120.26	67.21	134.14
Diameter	Uncoated	Mean (μm)	28.65	19.70	20.69
		CV_L (%)	33.03	26.21	28.20
		Min (μm)	16.61	15.53	15.47
		Max (μm)	45.37	25.46	26.13
	Coated	Mean (μm)	22.91	21.95	24.90
		CV_L (%)	19.74	10.59	13.73
		Min (μm)	17.90	16.73	20.06
		Max (μm)	35.23	25.63	31.29

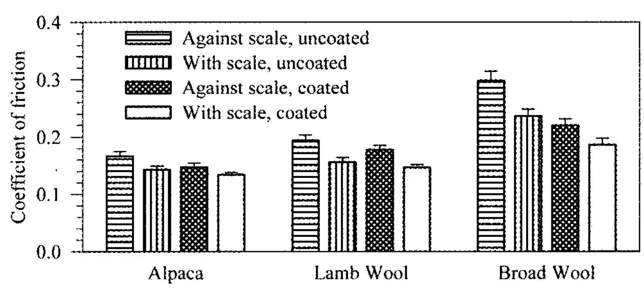

Figure 1. Effect of vapor coating on the static coefficient of friction of wool and alpaca fibers.

Table 2. *P* values of one factor analysis of variance of static coefficient of friction between coated and uncoated groups

	Alpaca	Lamb's wool	Broad wool
Against scale	0.013	0.005	<0.001
With scale	0.017	0.045	<0.001

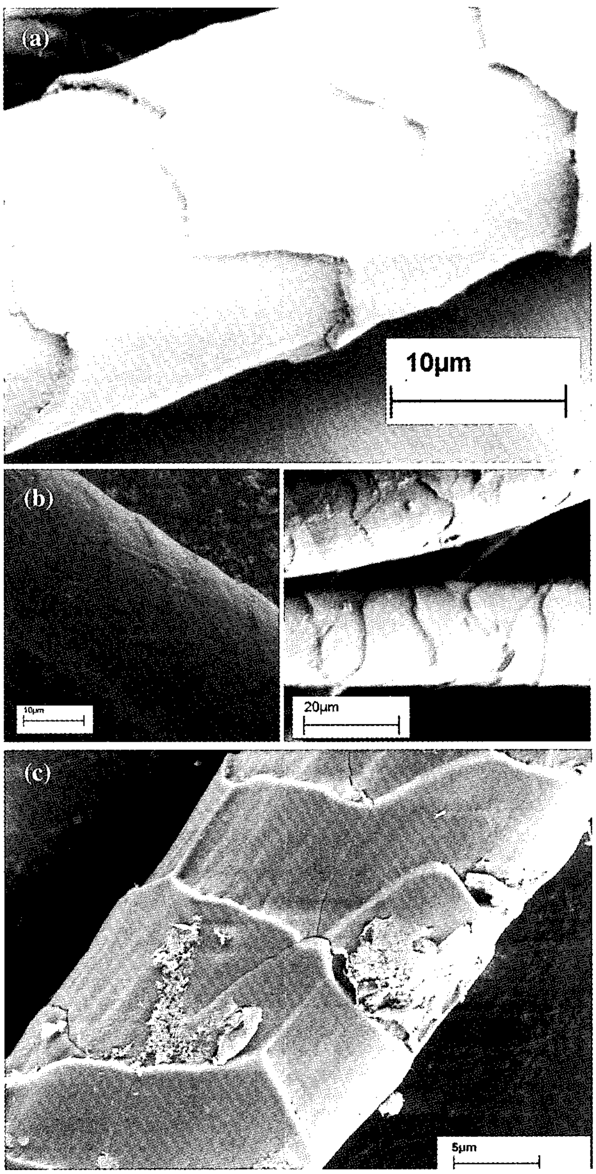

Figure 2. (a) SEM image of uncoated wool fiber-scales make fiber surface rough. (b) SEM image of coated wool fibers-conducting polymer layer smoothes the fiber surface. (c) A detailed surface morphology of polypyrrole coated wool fiber.

the coated and uncoated pair are statistically the same, is less than 0.05. This is because the conducting polymer coating layer smoothes the fiber surface (Figure 2). It partially covers the scales and forms a transition hump at the scale tips, which levels the fiber surface. Test results also showed that the coefficient of kinetic friction also reduced due to the conducting polymer coating.

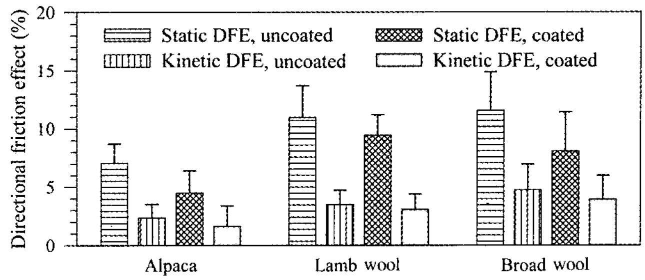

Figure 3. Directional friction effect of vapor coating on the wool and alpaca fibers.

Figure 1 also shows that the coefficients of friction of alpaca fibers are significantly smaller than the wool fibers even though the overall alpaca fiber diameter is greater than the wool fiber diameter (Table 1). This is because alpaca fiber has a higher scale frequency and lower scale height than the wool fibers [12].

Conducting polymer coating also reduces the directional friction effect (DFE) of wool and alpaca fibers as shown in Figure 3. This also suggests that the conducting polymer coating layer smoothes the fiber surface.

Tensile Properties of Single Fibers

Figure 4 and Table 3 show that conducting polymer coating on wool and alpaca fibers does not affect the fiber tensile properties to a large extent. The tenacity and initial modulus of Broad Wool, as well as the elongation of alpaca fiber, significantly increase due to the conductive polymer coating. There is no statistically significant difference in tensile properties between coated and uncoated lamb's wool fibers. It can therefore be concluded that the mechanical property changes due to conducting polymer coating on animal fibers may depend on the fiber type. In general, coating of conducting polymer on the wool and alpaca fibers will not lead to any loss in their tensile properties. In some cases, it may enhance the mechanical properties.

Figure 4(c) shows that the initial modulus of alpaca fiber is higher than wool fiber and the initial modulus of lamb's wool is the smallest. This is attributed to the difference in fiber diameter. Usually, when the mean fiber diameter increases, the initial modulus also increases and wool fiber becomes harsher. Table 1 clearly shows that the lamb's wool has the smallest mean fiber diameter.

As mentioned in the introduction, the conductive polypyrrole coated wool yarns have higher stress/tenacity, higher breaking strain and lower initial modulus than uncoated yarns [8], and the tensile properties of broad wool fiber follow exactly the same trend as the wool yarn even though different wools and coating methods are used.

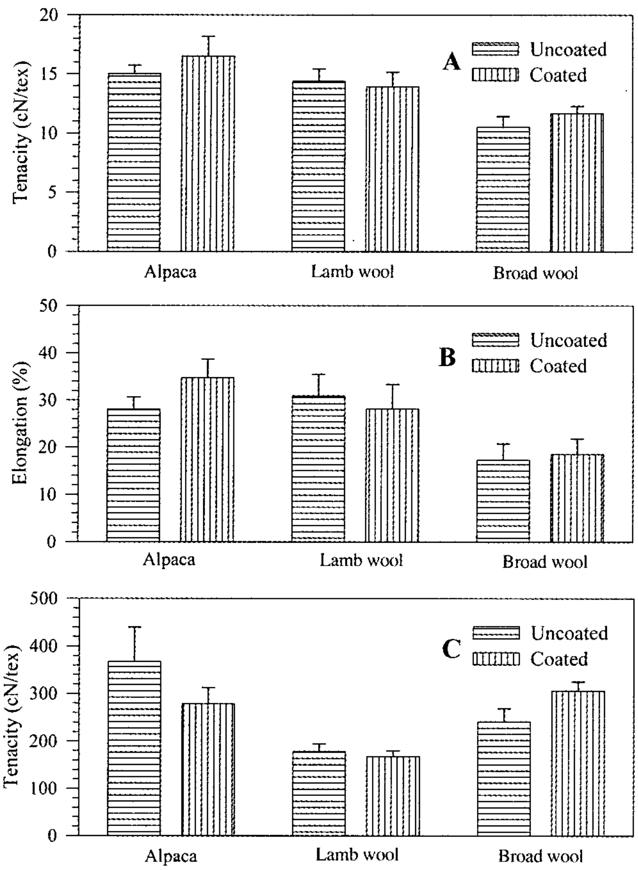

Figure 4. Change of fiber tensile properties.

Table 3. *P* values of one factor analysis of variance of tensile properties between coated and uncoated groups

Fiber	Tenacity	Elongation	Initial modulus
Alpaca	0.059	0.007	0.16
Lamb wool	0.53	0.42	0.24
Broad wool	0.038	0.59	<0.001

As shown in Figure 5, both wool and alpaca fibers have a higher breaking stress than the polypyrrole film. However, the tenacity of coated fibers tends to be higher than the uncoated fibers (Figure 4a). This may be attributed to the reinforcement effect of polypyrrole.

Figure 5 also shows that wool and alpaca fibers are highly extensible while the conductive polypyrrole is brittle. However, the polypyrrole coating layer does not lower the elongation of coated fibers (Figure 4b). This may be due to the fact that the polypyrrole layer is very thin (about 0.2 μm), as determined by TEM method [6].

Conclusion

By coating a thin layer of polypyrrole on the surface of wool and alpaca fibers, fiber morphology, frictional and tensile properties are altered. The coated conducting polymer layer covers the fiber surface and forms smooth transitions at the tips of the scales. This results in a significant reduction in the fiber coefficient of friction. It also reduces the directional friction effect of the fibers. Though it is brittle in nature, the existence of polypyrrole coating on the fibre surface does not cause embrittlement or loss of strength in fibers. On the contrary, the coating may slightly enhance or remain the tensile properties of fibres.

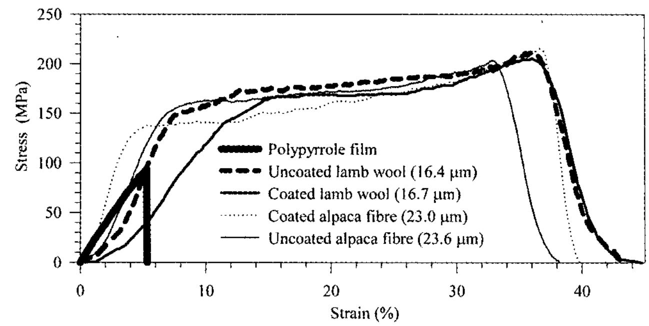

Figure 5. Tensile curves of a polypyrrole film (10 mm gauge length), and uncoated and polypyrrole coated lamb's wool and alpaca fibers (varied gauge length).

References

1. D. De Rossi, A. Della Santa, and A. Mazzoldi, *Mater. Sci. Eng.*, ***C*** **7**, 31 (1999).
2. A. Kaynak, G. A. George, and L. Rintoul, *Mater. Res. Bull.*, **35**, 813 (2000).
3. J. Joo, J. K. Lee, J. S. Baeck, K. H. Kim, E. J. Oh, and J. Epstein, *Synth. Met.*, **117**, 45 (2001).
4. A. Pron and P. Rannou, *Prog. Polym. Sci.*, **27**, 135 (2002).
5. G. Appel, A. Yfantis, W. Gopel, and D. Schmeisser, *Synth. Met.*, **83**, 197 (1996).
6. T. Lin, L. Wang, X. Wang, and A. Kaynak, *Thin Solid Films*, In Press, 2004.
7. A. Malinauskas, *Polymer*, **42**, 3957 (2001).
8. A. Kaynak, L. Wang, C. Hurren, and X. Wang, *Fibers and Polymers*, **3**, 24 (2002).
9. S. K. Dhawan and D. C. Trivedi, *Bull. Mater. Sci.*, **16**, 371 (1993).
10. A. Kaynak and R. Beltran, *Polym. Int.*, **52**, 1021 (2003).
11. M. Saurin and S. P. Armes, *J. Appl. Polym. Sci.*, **56**, 41 (1995).
12. X. Liu, L. Wang, and X. Wang, *Text. Res. J.*, **74**, 265 (2004).