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Effect of surface modification on frictional properties of polyester fabric

Subrata Mondal [a], Vamshidhar Reddy [a], Arpita Sarkar [b], Perincheery Aravindakshan [b], Animangsu Ghatak [a,*]

[a] Department of Chemical Engineering, Indian Institute of Technology, Kanpur 208016, India
[b] Unilever R&D, Bangalore 560066, India

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ABSTRACT

Characterization of frictional characteristics of textile fabrics is difficult because of surface heterogeneity in both topography and the surface chemical character, nevertheless important for tactile sensing and aesthetic appearance. Here we have addressed this problem by carrying out systematic sliding experiments on different fabrics and analyzing the data in terms of two new parameters. In particular, we have used two different types of polyester fabric which have been subjected to different surface treatments. Aqueous dispersions of hydrophobic metal-soap particles and long-chain cationic surfactant were used to modify their respective surfaces to desired extent. By sliding a soft elastomeric indenter against these fabrics over a large range of normal load, we have obtained the corresponding shear load and friction coefficient. Owing to the undulating topography of the fabric surface, both these parameters exhibit random fluctuation, so that describing such surfaces with a constant friction coefficient does not appear practical. Instead, we show that the surfaces can be characterized by the distribution of friction coefficient and the amplitude of the dominant mode of the fluctuations. These two parameters not only distinguish between different fabrics and differently treated fabrics but also quantify the extent of the treatment.

1. Introduction

As humans, whenever we encounter a new surface, for example a fabric, we first sense it visually and then feel it by touch. The feeling of touch or "tactile sensing" is of immense importance in almost every aspect of our lives and particularly for fabrics that come into direct contact with the skin in the context of clothing comfort [1]. Clothing comfort is one of the important concerns for textile and garment manufacturers. Comfort is based on the human sensory response to clothing materials and is determined by a variety of mechanical, thermal and physiological parameters [2,3]. Assessing textiles by touch is commonly known as 'fabric handle' which was defined by the Textile Institute in 1975 [4]. Fabric handle or feel is undoubtedly influenced by the static and dynamic friction between the fabric surface and the skin. During the evaluation of the tactile properties of textiles, contact is made through the skin where numerous mechano-receptors are located which give rise to various sensations felt by the human subject. The human finger is a sensitive device capable of detecting small differences in the frictional behaviour of fabrics [4–6]. The results from hand tests are as "smooth", "rough", "soft", "harsh", "clingy", "sticky", etc., depending upon the sense of touch which is primarily subjective and thus, does not always produce consistent results that can be used as meaningful guide for manufacturing and designing textiles of consistent quality. As a result, there has been significant interest to objectively quantify the 'tactile feel' or the 'fabric hand'.

The Kawabata Evaluation System (KES) [9,14] has been used with some success to objectively estimate the fabric hand. In KES, the fabric sample is held taut by applying tension at ends. A detector is then slid against the fabric while being tightly pressed against it. The coefficient of friction, geometric roughness and standard deviation of friction coefficient can be readily obtained as outputs. Detail analysis of the system relating in plane tensile stress in the fabric and its roughness to the frictional stress and friction co-efficient has not been carried out. In fact, it is not clear if a single friction coefficient can sufficiently characterize a fabric. Many researchers have used Instron tensile tester fitted with frictional assembly and a friction sledge to determine frictional parameter of the fabric [2,7,8,11,13,15,16,18,27,35,36,40]. The range of preload applied on the sledge and the sliding velocity used in the above reported methods are relatively higher than that applied on the human finger when used for characterizing tactile

* Corresponding author.

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sensation of fabrics. For instance, Ajayi worked with a sledge covered with fabric at an applied preload of 25 g and at a sliding speed of 5 cm/s [7]. Hermann et al. used a poly (methyl methacrylate) sled to characterize the frictional properties of fabrics [15]. Ramkumer et al. studied the frictional properties of fabrics with artificial finger tip (sled) made by polyvinylsiloxane at different applied preloads ranging from 39.64 g to 89.64 g at a scanning velocity of 0.83 mm/s [40]. Nair et al. worked at an applied preload of 30 g and at a sliding velocity of 50 mm/min between a tensile tester and cotton fabrics [35]. Ke et al. investigated the frictional behaviour of fine medical compression stockings against the forearm skin at different preloads ranging from 0–10 N and at different sliding velocities ranging from 50–150 mm/s [36]. Das et al. observed that the value of coefficient of friction decreased with increased preloads ranging from 60 g to 100 g for 8 commercial woven and knitted fabrics with different blends but similar structures [18]. Researchers have also developed several devices and experimental set-ups which can predict fabric stiffness, smoothness, or softness, and simulate the feeling of touch through friction measurements [10,12,17–31,34,37–39]. All these methods have been aimed at characterizing fabrics into different types. However, it is noted that industrially, fabrics are also treated with different chemicals for enhancement of their surface smoothness. To evaluate the efficiency of these treatments and the degree of smooth "feel" generated after the treatment, a quantitative measure of surface friction of soft fabrics is necessary. Currently there are no suitable tools or methods for definitive quantification of these parameters for the wide range of fabrics manufactured and processed in textile industries. The problem is indeed complicated as the fabric surface is heterogeneous, anisotropic and the frictional characteristics of one surface from another may not be significantly different yet their "tactile feel" may be different. It is in this context that we present a novel method of characterizing fabrics made of the same material but treated with different concentrations of chemicals for enhancing surface smoothness, based on the fact that surface treatments lead to changes in surface wettability of the fabrics, which in turn impacts the frictional behaviour of the fabric. From this information of the friction co-efficient, we can characterize fabrics according to their tactile feel.

For our experiments, we have chosen two different fabric samples made namely, Bombay Polyester (BP) and woven polyester (WP), both subjected to varying degrees of aqueous dispersions of hydrophobic metal-soap particles and long-chain cationic surfactant treatments. The range of applied preloads was varied from 0.009 N to 0.1 N, very much similar to that exerted during actual human touch (force of 0.2–0.8 N) using a very soft indenter whose elastic modulus (2.4 MPa) is comparable to Young's modulus of human skin (4.46 MPa) [19,20]. Sliding of this soft indenter on the different fabric samples results in obtaining shear load as a function of the normal load on the indenter. The shear load and friction coefficient do not remain constant but fluctuate with sliding. We have characterized these fluctuations by obtaining the probability distribution of the friction coefficient and its mean value, both of which remain distinctly different for different surfaces and vary systematically with the surface treatments. In addition, we have obtained also the FFT of the shear stress data which also show that the amplitude of the primary mode of fluctuation varies systematically, suggesting that it can be a useful parameter for characterizing not only the type of surface treatment but also the extent of such treatments.

2. Experimental section

2.1. Materials

Poly (dimethylsiloxane) (Sylgard, Dow corning product) (PDMS) was used for preparing soft, hemispherical, elastomeric indenter. A microscope glass slide coated with the monomolecular layers (SAM) of octadecyl trichlorosilane (procured from S.D. fine-Chem Limited) (OTS) was used as substrate for preparing the indenter. HPLC grade chloroform procured from S. D. fine-Chem Limited was used as a solvent for extraction of uncrosslinked molecules from the cross-linked elastomer. Two different types of polyester fabrics, namely Bombay Dyeing polyester (100% polyester, procured from Bombay Dyeing Industries, India, represented by BP) and Woven polyester (100% polyester, woven, procured from CFT, Netherlands, represented by WP) were used as substrates for different surface treatment and friction experiments. An aqueous dispersion of STEPANTEX®SP-90, procured from Stepan Company represented as SP, was used for treatment of the fabrics. STEPANTEX®SP-90 is a cationic surfactant ideal for producing fabric softeners and textile softening auxiliaries. Another aqueous dispersion of hydrophobic metal soap particles, represented as HP, was also used for treating the fabrics.

2.2. Method of treatment of fabric

Fig. 1 shows the scanning electron micrographs of the two types of fabric used in the experiments. In essence, both of them consist of two distinct sets of yarns: warp and weft yarns, which lie lengthwise and crosswise respectively [20]. The aerial density of the weft and warp yarns, their relative orientation, the weave structure, yarn fineness and pattern are important parameters in the context of friction but are hardly amenable to precise control. Furthermore, the yarns themselves are made of finer fibrils which can be of similar or different cross-sections and possibly consists of even finer fibres. Together they render the fabric hierarchically structured but also highly heterogeneous and anisotropic both in terms of surface topography and material characteristics like porosity, in plane and out of plane deformability and importantly friction characteristics. Therefore, in order to derive meaningful results from experiments, the sliding experiments were all carried out in the direction of weft yarns for WP and wrap yarns for BP fabrics respectively. In order to treat these fabrics uniformly through-out their area, they were cut into (10 cm × 10 cm) swatches. These swatches were stapled onto ballast fabric (polyester shirts, 3.5 kg total weight) and washed in a front loading automatic washing machine (IFB Senator DX, 6 kg). Different weights of the aqueous dispersions SP and HP were added separately during the third rinse of every wash cycle. Deionized water was used for washing and rinsing. 65 g of Persil Bio powder (Market sample) was used for the washing cycle (standard 40 °C cottons cycle). After treatment the swatches were dried and then ironed before performing the sliding experiments. Both the aqueous dispersions, namely, SP and HP were used in different quantity, e.g. 5, 10, 20, 40, 60, 80, 100 g with 20 l of water for treating the polyester fabrics and the corresponding treated fabric are represented by S_nBP and H_nBP respectively. For example, S_{50}BP represents Bombay Dyeing polyester fabric treated with 50 g of an aqueous dispersion of SP in 20 l water (added during the third rinse cycle). Similarly, H_{10}WP represents a woven polyester fabric treated with 10 g of an aqueous dispersion of HP. The SEM images of a typical WP fabric subjected to treatment with aqueous dispersion of the cationic surfactant and hydrophobic metal soap, that is SP and HP respectively, are depicted in Fig. 2. For treatment with SP it is clearly seen (Fig. 2b and c) that the surface of the fabric remains mostly clean except few very distinct patches of