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Contact and frictional properties of stratum corneum of human skin

Chien-Yu Chen[a], Chu-An Yu[a], Ting-Fu Hong[b], Yu-Lun Chung[a], Wang-Long Li[a,*]

[a]*Department of Materials Science and Engineering, National Cheng Kung University, Tainan, Taiwan*
[b]*Graduate Institute of Materials Engineering, National Pingtung University of Science and Technology, Pingtung, Taiwan*

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Abstract

Most skin tribology studies gave attention on the examination of frictional properties of normal and healthy skin surfaces. This study aims to investigate the frictional and mechanical properties of skin under different load and friction conditions after removing the stratum corneum from the designated uninjured forearm tissue by a tape stripping method. The influence of water on friction coefficient was explained by using adhesion model of friction. For quantifying the amount of removed stratum corneum from the skin surfaces, an UV/vis spectrum analysis was used to measure the absorbance and pseudo-absorbance of stratum corneum on the tape. To evaluate the influence of water on friction coefficient, trans-epidermal water loss (TEWL) value of different skin conditions was assessed by water evaporation measurements. Frictional and mechanical properties of the skin surfaces were acquired via a tribometer. Results revealed that the elastic modulus of skin decreased and the friction coefficient of skin increased with the increasing of the amount of removed stratum corneum. Friction force versus normal force was presented to explain the influence of water on friction coefficient and section change phenomenon of friction coefficient under different degrees of tape strips.

Keywords: Skin friction; Stratum corneum; Tape stripping; Trans-epidermal water loss

1. Introduction

Skin tribology plays an important role because human skin rubs against other external surfaces in our daily life, such as holding a ball [1], using skin care products [2], or touching a finger pad [3]. The comfort experience during the use of these products is closely related to the contact and friction behavior between human skin and product surfaces. The reciprocating sliding and contact between skin and working implements, sports appliances, improper footgear, and textile materials, etc., may lead to skin damage [2]. Therefore, a good understanding of skin tribology is important in the design of human–product interfaces that have tribological functionality and that are comfortable in use.

Skin is composed of three layers – epidermis, dermis and subcutaneous fat with anisotropic mechanical properties. The mechanical properties of epidermis are determined by stratum corneum, which is most external skin layer. Tape stripping is widely applied to dermatologically and pharmacologically study skin layers. The factors that influence the properties of the stratum corneum in tape stripping measurements are thicknesses of the stratum corneum [4], number of cell layers, cohesion between the cells [5,6], and tape stripping conditions (such as the number of tape removals [7], the profile and duration of the force press on the skin [8], indentation depth [9], evaluating facial cleanser [10], and type of tape used [11,12]). Quantitative studies for practical conditions have been conducted [13–15] on the mechanical and frictional behavior of human skin. Not only the type of skin (hard and soft, age [16], gender [17]) and skin conditions (e.g., hydration state, sweat, sebum level) [18] affect skin properties, in addition, the hydrophilic/hydrophobic interface between human skin and contacting surfaces also affects skin frictional properties [19,20]. Research on grip and tactile sensation of

*Corresponding author. Tel.: +886 6 2757575x62951; fax: +886 6 2346290.
E-mail addresses: li.dragonpuff@gmail.com, wlli@mail.ncku.edu.tw (W.-L. Li).
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human skin on friction has increased due to the popularity of touch interfaces and mobile devices [21]. Various factors that influence the friction behavior of human skin have been discussed by a tribometer, such as sliding speed [22] and materials of rotating disc and probe [23,24].

Forearm skin is representative of non-glabrous skin and has low hair fiber density, thus the frictional properties of forearm skin with a smooth surface have been commonly reported. This study evaluated the mechanical and tribological characteristics of tape-stripped forearm skin. Pailler-Mattei et al. [9,25] also studied skin tribological behavior in vivo after the tape stripping procedure. However, the measuring method of stratum corneum removed from the forearm is different. In Refs. [9,25], tapes were weighted before and after the stripping procedure in order to measure the amount of SC removed. However, the weight of tape is determined not only by the corneocyte aggregates, but also sebum, lipids, and sweat [8]. Since corneocyte aggregates represent the basic of stratum corneum on a stripped tape, this study applies the method of combining tape stripping and spectroscopy proposed by Weigmann et al. [8] to measure the mass of the corneocyte aggregates on the tape. Refs. [9,25] showed the importance of the electric charges on skin biotribological behavior. Electric shear strength was added to friction adhesion component. Thus, a physical model was derived to evaluate the friction electric force. The electric shear strength values to calculate the skin friction coefficient after the tape stripping. To quantify the mass of stratum corneum removed from the skin surface and to evaluate the influence of water on friction coefficient, an ultraviolet/visible (UV/vis) spectrometer was used to measure the protein absorption with the decreases of the amount of stratum corneum and the trans-epidermal water loss (TEWL) of each tape strip. Several factors can influence the quantity of stratum corneum that is removed by a piece of tape. In this study, we focus various tape-striping skin by coupling changing probe sliding velocity and normal load, which are not discussed in [9,25]. Eventually, friction force versus normal force was presented by using the adhesion model of friction to explain the influence of water on friction coefficient and section change phenomenon of friction coefficient.

2. Experimental setup

2.1. Skin samples

In the experiment, the skin sample was chosen from the inner forearm skin of a healthy 26-year-old man. The skin sample was not treated with any chemical/cosmetic substances in the 24 h before the experiment and not exfoliated in the month before testing to retain its natural conditions. Before each test, the skin was preconditioned and was washed with water to remove impurities and dried at room temperature (22–24 °C) with a relative humidity of 45–55% for approximately 30 min. Notably, sebum existed on skin surface, if the skin washed with water. Sebum on lipidic film affected the skin adhesion behavior due to capillary phenomena reported in [9,25], and should be further investigated. The friction tests were carried out on the inner forearm, at 5 cm from the wrist. Before the procedures and measurements of the studies began, the volunteers rested for acclimatization for at least 30 min in the test room. Informed consent was obtained, and this study was approved by the ethics committee of the National Cheng Kung University. It is well-known that friction measurements could vary from one human to another. The tests were carried out only on one volunteer, which was not conducive to statistical analysis of data. However, to compare the general frictional performance of the different agent–surface combinations under the various test conditions, using one subject would be appropriate.

2.2. Tape stripping

Commercially available adhesive tape was utilized in this study (DEER BRAND®, Symbio Inc., Taiwan). The tape consisted of biaxially oriented polypropylene and a solvent-based acrylic adhesive. The adhesive film had a length of 30 mm and a width of 19 mm. The tape was applied to the identical skin area and pressed for 10 s before peeling off from the skin in a fixed direction. The peeling speed was of 20 mm/s. Tape samples were collected after every 5th, 10th, 15th, and 20th times stripped, respectively, for the following experiments.

2.3. Indentation and friction tests

Indentation and friction tests were carried out by a nano/micro-tribometer (UMT-2, Bruker) (Fig. 1 left). Indentation test was applied to measure the normal stiffness of forearm skin. During the indentation (loading/unloading) process, the applied normal load F_z was increased from 0 to 196 mN, and the probe returned to its initial starting position at the unloading state at the end of each test. The indentation depth was recorded as a function of the normal force. The normal contact stiffness can be evaluated by calculating the slope of the initial portion of the unloading curve:

$$k_z = \frac{dF_z}{dz} \tag{1}$$

where z is the indentation depth and F_z is the normal load. The reduced elastic modulus E^* of the indented skin can be obtained from the slope of the initial portion of the unloading curve k_z of the load–displacement curve, as proposed by Oliver

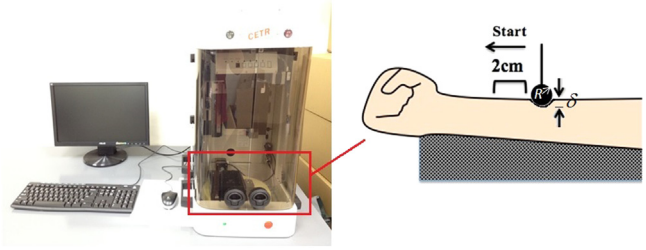

Fig. 1. UMT-2 tribology device setup (left), and test position of forearm skin (right).