

Chapter 10

Analogy of Mechano- Tribological Behavior of Different Locomotor Surfaces

ABSTRACT

In this chapter, we compare two locomotor surfaces: snake and human within the context of mechano-tribological behaviour. We show that the friction response of both skins is similar despite difference in composition and apparent surface structure. Both skin types display sensitivity to hysteresis and adhesive dissipation. Human skin, however, being more sensitive to hysteresis than snakeskin. The ratio of friction coefficients, when sliding on the same interface, is a function of the reciprocal of the moduli of elasticity. This points at the effect of the layering sequence of skin compositional layers which results in functional grading of properties to facilitate efficient performance under species specific constraints.

INTRODUCTION

Skin in vertebrates and inter-vertebrates manifest complex composition. It comprises arrays of collagen fibers arranged in various patterns. Arrays of collagen and elastin are common in skin of many species (human, worms, fish, etc.). Collagen fibers assume several shapes (straight, convoluted, or crimps). They are arranged in patterns of various degree of randomness (Vincent, 2012) Despite sizeable variation in structural patterns, the stress strain curve of almost all skin types is of a universal form (the so-called J-shaped stress-strain curve) (Wainwright, 1982).

Mai and Atkins (*Mai and Atkins, 1989*) analyzed the energetics of the J-curve at each interval of its evolution during tensile tests. They observed that within the early stages of this type of stress-strain curve, strain is almost independent of stress. This implied the lack of shear connection in the particular material. Lack of shear connection prevents the concentration of energy into the path of a putative crack. Lack of shear connection, equivalent to lack of shear stiffness in anisotropic solids, is the origin of high tear resistance of skin.

Friction is an interfacial phenomenon within which a shearing force performs work on an effective volume of two complying materials. This effective volume includes the surface layer of the skin as well as several sublayers that support the normal complying load. Dissipation of the friction-induced-work takes place within the sub-layers along a path that depends on the pattern of the fiber-elastin matrix

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comprising the skin. The universal behavior of the stress strain curve for the skin implies also a universal behavioral trend in shear loading and thereby in friction. That is, one may anticipate that the mechanics of accommodation frictional loads in skin are universal regardless of the species.

In the past three decades or so, considerable work that probe friction behavior of human skin took place. The general motivation of these efforts varied between cosmetics (Dowson, 1996, Timm, et al., 2011, Abramovits, et al., 2000, Bhushan and Tang, 2011, Bhushan, et al., 2005), healing of burn and wounds (Korinko and Yurick, 1997; Herst, 2014; Rogachefsky and Taylor, 2000; Zhang and Mak 1999, Derler, et al., 2015.), prosthesis (Mak, et al., 2001; Zhang and Roberts 1970; Filep. et al., 2016), and haptics (Derler and Gerhardt, 2012; Schreiner et al., 2013; Tang et al., 2015; Darden and Schwartz, 2015; Yoon, et al., 2016) among other things. Understanding the sense of touch and reaction of skin to fabrics was another major motivation (Gerhardt, et al., 2008; Hendriks and Franklin, 2010; Derler et al., 2009; Guerra and Schwartz, 2012; Soneda and Nakano, 2010; Frackiewicz-Kaczmarek, et al., 2015). Recently the problem of developing synthetic skin assumed considerable momentum. Several works that compare the friction of human skin to several synthetic skins started to emerge in the literature (Van Der Heide et al., 2010; Cottenden and Cottenden, 2013; Bostan et al., 201; Gerhardt et al., 2009; Wang et al., 2014; Nachman and Franklin, 2016; Shirado, et al., 2007). Tribology literature however still lacks studies where the friction behavior of skin from different species is cross correlated. In fact, few studies that consider skin of animals or reptiles is not frequently encountered to start with. Of the existing studies, only a few animal skin have been investigated (e.g. few reptiles, porcine and rat (Chen and Bhushan, 2013; Lijie and Pan, 2009; Xiao et al., 2014; Benz et al., 2012; Abdel-Aal, et al., 2010; Abdel-Aal et al., 2011; Abdel-Aal, and El Mansori, 2014; Klein and, Gorb, 2014)). Cross correlation of human skin performance to performance of other skin types is a very active topic within transdermal drug delivery.

A primary objective in the design and optimization of dermal or transdermal drugs is to understand the mechanics of “in-vivo” performance. When the drug is designed for humans, it is essential evaluate percutaneous absorption of molecules. The best prohibit experimentation with human subjects within the initial development stage. A challenge, therefore, arises since the option at this stage is to find a plausible correlation between “ex-vivo”, animal and human studies for prediction of percutaneous absorption in humans (Godin and Touitou 2007). Consequently, considerable investigations took place within the past four decades to assess the permeability of many biomaterials in comparison to human skin. The list includes, primates, porcine, rodents, guinea pigs and snakeskin (with porcine skin being frequently showing many similarities to human skin (Gray, and Yardley, 1975; Dick, and Scott, 1992; Muhammad, et al., 2004; Lin et al., 1992; Netzlaff, et al., 2006; Sandby-Moller, et al., 2003; Simon, and Maibach, 2000)).

Higuchi and Kans (Higuchi, and. Kans, 1988) were the first to propose shed snakeskin as a barrier membrane in-vitro permeation study. Following their lead, several researchers incorporated shed snake-skins in their experimental protocols. Skin from several snake species, *Elaphe obsoleta* [Itoh, et al., 1990; Bhattachar, et al., 1992; Bhatt, et al., 1991; Harada, et al., 1993; Pongjanyakul, et al., 2002), have been investigated. Haigh et al. (Haigh, et al., 1998) investigated the effect of species, sites, and body regions of the shed snakeskin on measurements and their relation to actual performance of human skin. Haigh reported good correlation to human skin. He suggested the use of shed snakeskin as a model membrane for permeation studies despite anatomical differences and chemical compositions (Turunen, et al., 1993).

Trans-dermal diffusion is a time-dependent phenomenon that initiates at the skin surface (i.e. at the level of the micro-topography (roughness)). The process starts by the diffusing substance attempting to occupy the void space between the roughness features of the target surface. Roughness features (or micro-

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