Chapter 12

Review of Friction and Surface Properties of Snakeskin

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ABSTRACT

Locomotion is an essential activity in the biological world. Friction affects the energy invested in motion. Natural systems tend to conserve energy. As such, it is necessary to mitigate the effects of friction. There are many intriguing examples of creatures where dynamics of motion and surface geometry (macro and micro) combine to optimize the tribological profile. One example is that of snakes. In snakes, texturing geometries and topologies specifically contribute to frictional mitigation in a variety of situations. Snakes are found everywhere on earth. Their diverse habitat presents a broad range of tribological environments. This requires customized surface design features that potentially can inspire deterministic solutions for many technical problems. Therefore, they have attracted attention lately. Many, from surface engineering to robotics, have started to study their tribological response and frictional characteristics. This chapter attempts to review the major findings about the tribology of the legless reptiles obtained through the last two decades.

INTRODUCTION

Allah has created every creature from water. And of them are those that move on their bellies, and of them are those that walk on two legs, and of them are those that walk on four. Allah creates what He wills. Indeed, Allah is over all things competent. (Quran 24:45)

Snakes have a wide distribution all over the planet. They are found almost everywhere on earth except where factors that limit their survivability are present (e.g., higher altitudes where very cold temperatures are predominant year round). Their ecological diversity, and thereby their diverse habitat, presents a broad range of tribological environments many of which are hostile in terms of sliding and contact conditions. Hostility and diversity require specific tribological response that manifests itself in functional practices.
and surface design features. As such, they offer a great resource that can be mined for viable surface design inspirations, which address a wide spectrum of technical problems, faced in the technical world.

The motion of a snake is a delicate balance between the propulsive forces generated by the muscles and the friction tractions due to contact with the substratum. In some cases, the snake makes use of friction to generate thrust. However, for economy of effort, the COF needs to be minimized (especially in rectilinear locomotion) since friction opposes motion. As such, a self-regulating mechanism to control frictional tractions should exist in the snake. The texture of the surface (i.e., the micron sized fibril structures or denticulations) are a major component of such a mechanism. The geometry and topology of the fibril structures allow the snake to modify the frictional profiles in response to changes in contact situations. The presence of the fibrils contributes to the dynamic control of the real area of contact between the skin and the substratum upon sliding. The function of the denticulations (micron-sized fibrils) in this sense is similar to that of the deterministic textures used to regulate friction.

Frictional performance of snakes was a subject of several investigations that confirmed the unique features of the ventral skin of snakes and their optimized tribological response with respect to energy losses and resistance to abrasion and wear (Abdel-aal, 2013; Abdel-aal, et. Al, 2011, 2012; Klein & Gorb, 2012; Benz et. al, 2012; Schmidt & Gorb, 2012) Other results (Abdel-aal, et. al 2011; Schmidt & Gorb, 2012; Stewart & Daniel, 1973; Abdel-aal & El Mansory, 2011) attribute optimization of tribological function to the geometrical patterns and metrology of ventral scales. Frictional response in snakes is the culmination of functional specialization in terms of surface microstructure and metrology.

Ventral scales in snakes have hierarchical micro-geometry in that the scales contain arrays of micron-sized fibril structures (Abdel-aal et. al. 2011, 2012; Benz et. al., 2012; Abdel-aal, 2015; Berthe et al, 2009). The geometry and topology of these fibrils allow the snake to modify the frictional profiles in response to changes in contact situations (Abdel-aal, 2013.; Abdel-aal & El Mansory, 2011). The presence of the fibrils contributes to the dynamic control of the real area of contact between the skin and the substratum upon sliding. The function of the denticulations (micron-sized fibrils) in this sense is similar to that of the deterministic textures used to regulate friction. This similarity raised the curiosity of several researchers (Stewart & Daniel, 1973; Abdel-aal & El Mansory, 2011, 2014). The results pointed many common features between man textured surfaces and micro-ornamentation in ventral scales. Namely, the research pointed at the deterministic nature of the topology of the micro-texture of the scales. The building block of the micro-texture is a 3-D feature of primitive geometry. The feature repeats on the surface in a particular topological pattern so that the metrological description of the surface reduces to several deterministic attributes almost identical to those used for textured surfaces (Marvi, H., Gong, C., et al, 2014; Cicconofri et al, 2015; Rezapour, et. al, 2014, Toyoshima, et. al, 2014, Liljeback et. al., 2014; Virgala, et. al., 2014; Bogue et. al. 2014).

There are several similarities between a textured engineering surfaces TES and the ventral side of a snake, both in metrology and topology. The main similarity is the dependence of the metrological features on the scale of observation. That is both of the snakeskin and the LTS belong to the so-called multi-scale surfaces. In addition, the basic building block in each case (snakeskin and TES) is a textural element that is repeated in an array distribution. The snake’s ventral side is composed of identical micron-sized fibrils (denticulations) distributed over the skin area in a particular pattern. Spacing, length, orientation and shape of denticulation is in general common to a particular family of snakes. TTS, on the other hand, by their very definition comprise an individual textural building block (cone, dimple, chevron etc.,) that also is distributed on the surface area in array form. Therefore, both types of surfaces share a common constructal origin. A snake, however, has to be self-sustaining over a wide spectrum of sliding