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Nature inspired design in tribology

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ABSTRACT – In recent years, biomimetic has gained attention in the field of science and technology. It has been grown into diverse areas ranging from micro- to nano-electronics to structural engineering and now rapidly emerging in the field of tribology. The present article provides examples of bio-inspired topics and recent developments related to tribology. It covers the details of bio-inspired surfaces and properties that exhibit high wear resistance, low or high adhesion and the friction properties at micro- or nano-scales. Successful examples of animal- and plant-inspired inventions are discussed in great detail.

1. INTRODUCTION

Nature shows numerous examples of natural systems either in animals or plants which has efficiency of energy usage, superb structure design and optimum consumption of body part. For these reasons, the nature has been an important source of inspiration to develop artificial ways to mimic the significant properties of biological systems. There are many popular examples of biomimetic design from plants such as lotus, rose petal, rice leaf [1], silver ragwort and ramee leaf [2] and from animals i.e. shark skin [3], gecko [4] and insects. To date, biomimetic research has been directed towards tribology in terms of transferring technologies from biological systems into engineering applications with specific purposes. In tribology, the potential for biomimetics has been recognised in the diverse fields of robotics, mechanics, automotive and also surface engineering. This shows that tribological properties of a system could give a huge contribution in saving energy and increasing materials' service life. This article reviews the potential in mimicking the superb nature as an efficient and a durable system for potential engineering applicatio especially in enhancing tribological properties.

2. TRIBOLOGICAL DESIGN IN ANIMALS

Numerous excellent tribological properties have been observed in animals and insects specifically for the effect of adhesion and friction. Adhesion and friction interaction can be found in many insect and lizard species which possess adhesive organs on their feet that allow them to adhere to a wide variety of surfaces. The fast movement of a gecko for an example, on a vertical wall or tree demonstrates high adhesion and friction properties. This property is useful in designing climbing robots which has high potential use for surveillance and inspection in specific environments [5]. Tree frogs such as *Amolops sp*. possess large disc-like pads at the tip of their toes that assist them in attaching to leaves and trees surfaces. This design of toes can be found on automobile tires which creating sufficient grip during motion on wet road. Contrary to gecko, low adhesion properties of shark skin, dung beetle and some other animals which attribute to superhydrophobic properties make themselves always clean. This property is useful in producing self-cleaning devices. The v-shape riblet structure on shark skin effectively reduces friction between a solid surface and air. This property also helps the shark to move fast with low friction as it swims in water [6]. Another interesting example is the snake scales that can be beneficial when designing surfaces with anisotropic frictional characteristics. Even the low adhesion of a mosquito's eyes is superhydrophobic that can prevent itself from being covered with water in high humidity environment [7]. Focusing into wear of materials, to date, most researchers have focused on designing materials and textures that have excellent wear resistance. For instant, the mechanism of wear resistance of a mole cricket and pangolin could be used in the manufacturing of soil-engaging engineering components such as those in agricultural machinery and earth moving machinery. As reported in a literature, a sandfish living in a desert can moves rapidly as the scales on its body have superior sand erosion wear resistance [8].

3. TRIBOLOGICAL DESIGN IN PLANTS

Plant leaves exhibit special wettability and among them, lotus leaf (*Nelumbo nucifera*) or water lily is the most widely develop and promising [2]. The characteristic property of material that is superhidrophobicity and wettability of the solid surface strongly depends the surface energy and the surface structure with water contact angle, greater than 150° [9]. In plants, waxes function as the main transport barrier, preventing water loss and responsible for the wettability and self-cleaning properties, sliding of insects, reflection of visible light, adsorption of UV radiation and reduce the adhesion of particles [10]. Inspired by the lotus leaves, many synthetic superhydrophobic self-cleaning surfaces with a water contact angle more than 150° have been prepared by inventing appropriate surface morphology and roughness. Self-cleaning surfaces usage are limited by the micro- and nanoscale of superhydrophobic surface structures require low wear for the maintenance of material functionality, thus materials must be very wear resistant or have low friction [10].

By mimicking the nature, varietes of methods have been developed to fabricate superhydrophobic surfaces. The efforts were focused on surface texturing, in order to create a suitable micro/nano-roughness able to generate the superhydrophobic properties [11]. The most challenging part is to fabricate robust and durable superhydrophobic surfaces that suitable for application in many fields including barrier, anti-icing/fogging, water/oil separation, anti-bioadhesion materials.

Figure 1 shows some examples of superb tribological design in nature.

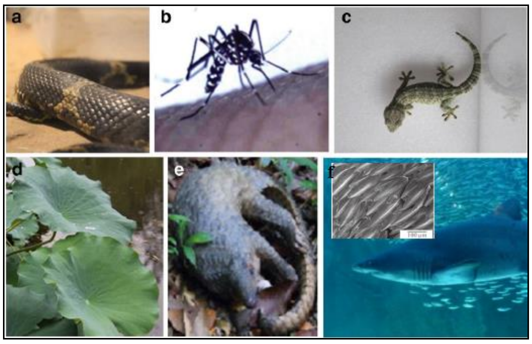

Figure 1 The examples of superb tribological design in nature; (a) snakes scale (b) mosquito (c) gecko (d) lotus leave (e) malayan pangolin (f) shark with its skin texture [8].

4. DESIGN METHOD

Fabrication of superhydrophobic and self-cleaning surfaces is considering in making a rough surface and modifying with a material with low surface energy. Biomimetic designs in producing superhydrophobic surface are tabulated in Table 1.

Table 1 Methods of biomimetic.

Animals/Plants	Author/Sources
Lithography – nanoimprint/ soft-photolithography	Jia et al., 2012 [12]
Templating	Shirtcliffe, et al., 2010 [13]
Plasma, Laser and Chemical Etching	Reinosa et al., 2013 [14]
Electrospinning	Jia et al., 2012 [12]

5. FINAL REMARKS

Biomimetics are being applied in diverse areas ranging from micro- to nano-electronics to structural engineering and now is emerging in tribology. The mechanisms of these biological phenomena are the optimal solutions to the corresponding living environments. Some examples of inventions that have already become technological solutions related to the field of tribology were discussed such as the lotus effects in manufacturing of self-cleaning devices, the gecko effects in fabricating wall climbing robots and high wear resistant of soil-living animals are beneficial in inspiring soil-engaging engineering machinery components productions.

6. REFERENCES

[1] K. Liu and L. Jiang, “Bio-inspired design of multiscale structures,” *Nano Today*, vol. 6, pp.155–175, 2011.

[2] X. Wang, B. Ding, J. Yu and M. Wang, “Engineering biomimetic superhydrophobic surfaces of electrospun nanomaterials,” *Nano Today*, vol. 6, pp.510–530, 2011.

[3] D. Zhao, Q. Tian, M. Wang and Y. Jin, “Study on the hydrophobic property of shark-skin-inspired Micro-Riblets,” *Bionic Engineering*, vol. 11 pp.296-302, 2014.

[4] D. Tao, J. Wan, N. S. Pesika, H. Zeng, Z. Liu, X. Zhang, Y. Meng and Y. Tian, “Adhesion and friction of an isolated gecko setal array: The effects of substrates and relative humidity,” *Biosurface and Biotribology* vol. 1, pp. 42–49, 2015.

[5] D. Sameoto, Y. Li and C Menon, “Multi-Scale Compliant Foot Designs and Fabrication for Use with a Spider-Inspired Climbing Robot,” *Journal of Bionic Engineering*, vol. 5, 189–196, 2008.

[6] R. A. Singh and E. S. Yoon, “Biomimetics in Tribology - Recent Developments,” *Korean Physical Society*, vol. 52, pp. 656 – 668, 2008.

[7] L. Yao and J. He, “Recent progress in antireflection and self-cleaning technology – From surface engineering to functional surfaces,” *Progress in Materials Science*, vol. 61, pp. 94–143, 2014.

[8] Z. Liu, W. Yin, D. Tao and Y. Tian, “A glimpse of superb tribological designs in nature,” *Biotribology*, vol. 1–2, pp. 11–23, 2015.

[9] Z. Guo and W. Liu, “Biomimic from the superhydrophobic plant leaves in nature: Binary structure and unitary structure,” *Plant Science*, vol. 172, pp.1103–1112, 2007.

[10] K. Koch, B. Bhushan and W. Barthlott, “Multifunctional surface structures of plants : An inspiration for biomimetic,” *Progress in Materials Science*, vol. 54, pp.137–178, 2009.

[11] E. Celia, T. Darmanin, E. T. Givenchy, S. Amigoni and F. Guittard, “Recent advances in designing superhydrophobic surfaces ,” *Journal of Colloid And Interface Science*, vol. 402, pp.1–18, 2013.

[12] Y. Jia, W. J. Nan, Y. Y. Hao, Y. Han and X. Ying, “Biomimetic fabrication and characterization of an artificial rice leaf surface with anisotropic wetting”, *Chinese Science Bulletin*, vol. 57, pp.2631–2634, 2012.

[13] J. S. Neil, G. McHale, S. Atherton and M. I. Newton, “An introduction to superhydrophobicity,” *Advances in Colloid and Interface Science*, vol. 161, pp.124–138, 2010.

[14] J. J. Reinosan, J. J. Romero, M. A. Rubia, A. Campo and J. F. Ferna´ ndez, “Inorganic hydrophobic coatings: Surfaces mimicking the nature,” *Ceramics International*, vol. 39, pp.2489–2495, 2013.