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Bio-inspired Superhydrophobic and Icephobic Surfaces: A Short Review

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ABSTRACT

In nature some biological surfaces shows very interesting properties, which inspire researchers in materials science. The Lotus leaf and Pitcher plant are identified as superhydrophobic and icephobic surfaces, respectively. Lotus leaf has hierarchical mirco-nanostructure which helps water droplet to roll off and spontaneously clean the surface. Pitcher plant secrets lubricant on its surface, when the water drop comes in contact with it. The Pitcher plant surface can act as lubricant-infused “slippery” surface which can be useful to repel ice from surface. Other biological surfaces such as butterflies wing, penguin feather, fish scale, gecko foot, mosquito eyes and many shows multifunctional property which inspire to researchers to mimic their extraordinary properties.

Keywords: Lotus Effect, Petal Effect, Penguin Feather, Superhydrophobic, Icephobic.

INTRODUCTION

In the nature, many plants, insects and animal surfaces repel water droplets and avoid the accumulation of dust and ice on their own body. Study on water repellent self-cleaning surfaces and an anti-icing surfaces have very interesting area of research. Generally, the basic theory of liquid adhesion on solid depends upon the wettability of liquid on solid surface. The water contact angle on smooth solid surface is less than 90° known as hydrophilic surface. On the other hand, water repellency increases with surface roughness. On hydrophobic surfaces the water contact angle is greater than 90°. If the water contact angle on solid surface exceeds 150°, such surfaces are known as superhydrophobic surfaces. There are two types of superhydrophobic surfaces, namely, Wenzel’s type surface (Wenzel, 1936) where the water droplet penetrate into the cavity of rough surface and cannot rolled off. In Cassie-Baxter type surface (Cassie, *et al.* 1944) the air layer present in between water droplets and solid surface, which reduce the liquid-solid interface area and water droplets roll off easily.

The mimicry of the extraordinary properties of biological surface can help to build the artificial smart surfaces with the help of nanotechnology.

1. Superhydrophobic Plants and Flowers

Lotus leaf is a famous example of water repellent and self-cleaning surface. Many research groups have reported that the surface of Nelumbo nucifera leaf (the lotus plant) has randomly distributed micropapillae of about 5–9 μm in diameter, enclosed by fine nanostructured wax branches of 120 nm in diameter. Due to micro- and nano-structure rough surface and presence of epicuticular wax, its surface is highly non-wettable with WCA > 150° and sliding angles < 10°. Water droplets freely move anywhere on the lotus leaf without pinning. The spherical water droplets on lotus leaf roll off with collecting dirt and clean the surface efficiently and this effect is famously known as *lotus leaf effect* or *self-cleaning effect* (Barthlott, *et al.* 1997, Darmanin, *et al.* 2015, Koch, *et al.* 2009). The lotus leaf shows self-cleaning property due to Cassie-Baxter state on the surface. Feng *et al.* (2002) have reported that, rice leaf is anisitropic water repellent surface. Rice leaf surface is covered with micropapillae which is nearly similar to micro- and nanostructure of lotus leaf surface. Micropapillae are arranged in one dimensional order parallel to edge of leaf and randomly in the other direction. The value of sliding angle are different for parallel to edge of leaf (3°-5°) and randomly in other direction (9°-15°). The Rose petals have hierarchical micro- and nanoscale structured roughness sufficient to achieve superhydrophobicity with a high adhesive force to water known as *petal effect* (Bhushan, *et al.* 2010, Feng, *et al.* 2008). The water droplet takes spherical shape on rose petals but cannot roll off. Feng and researchers have reported that especially petals of red rose (rosea Rehd) possess multifunctional properties, demonstrating superhydrophobicity, high water adhesiveness, and structural color (Feng, *et al.* 2008). In Fig. 1a shows a periodic array of micropapillae with an average diameter of 16 μm and height of 7 μm. In magnified SEM image, micropapillae exhibit cuticular folds in the nanometer scale having a width about 730 nm on each top (Fig. 1b). Spherical water drop on rose petal has shown contact angle 152.4°, which indicate superhydrophobicity (Fig. 1c). Rao *et al.* (2011) have prepared the transparent superhydrophobic silica films using sol-gel method. The water contact angle higher than 150° and sliding angle less than 10° were achieved on the silica coating. This superhydrophobic silica coatings were irradiated with high energy electron beam (~ 7 MeV). After irradiation the porous morphology was changed from porous to compact morphology and the wettability was also changed. After irradiation, the water contact angle was still higher than 150° however, the sliding angle changed drastically. The water drops hanged on the irradiated surface even after tilting the surface upside down.

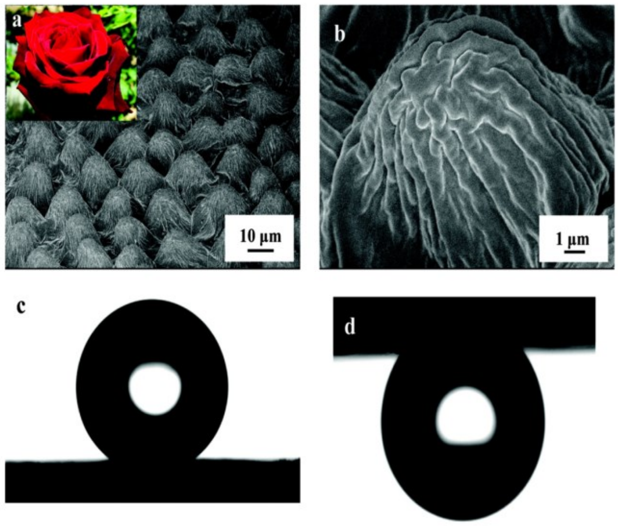

Fig. 1: (a, b) SEM images of the surface of a red rose petal. (c) Shape of a water droplet on the petal's surface. (d) Shape of water on the petal's surface when it is turned upside down. Images reprinted from (Feng, *et al.* 2008), with permission from American Chemical Society, Copyright 2008.

2. Superhydrophobic Animals and Insects

Some biological surfaces such as butterfly wings, fish scale, gecko foot, mosquito eye etc. also shows multifunctional properties. Many research groups (Potyrailo *et al.* 2007, Vukusic *et al.* 2003, Zheng, *et. al.*, 2007) reported that the morpho butterfly wing have multiscale photonic structures from nanometer, micrometer, to millimeter roughness. The multiscale structured surface shows superhydrophobic and self-cleaning property. The Goodwyn *et al.* (2009) have reported that butterflies wings have hydrophobic or superhydrophobic properties with different colors. The scales of the transparent butterfly wings of the genus Parnassius glacialis (Papilionidae) have not displayed clear pattern but for Parantica sita (Nymphalidae) showed highly organized lines forming periodic and parallel porous microstructures. Hansen *et al.* (2005) have demonstrated that toe of tokay gecko consist of millions of keratinous setae, each seta branches into hundreds of 200 nm spatula. The gecko setae shows self-cleaning properties because setae are adhesive and can self-clean when it dry. Liu *et al.* (2012) have reported that a gecko foot is superhydrophobic. Cai *et al.* (2014) have reported that the unique skin of a filefish Navodon septentrionalis shows anisotropic oleophobicity under water. Oil droplets tend to roll off in a head-to-tail direction on the rough surface of N. septentrionalis skin, but pin in the opposite direction. This type of surfaces has potential application in oil transportation, oil-repellent coatings, and water/oil separation (Cai *et al.* 2014).

Gao and co-researchers (Gao, X. *et al.* 2007) have reported that eyes of the mosquito C. pipiens possess ideal superhydrophobic properties that provide an effective protective mechanism for maintaining clear vision in a humid surroundings. The mosquito eye has a compound structure; single ommatidia consist of microscale hemispheres and ommatidia are uniform with a diameter of ca. 26 µm and they are organized in a hexagonally close-packed arrangement. Under SEM, each micro-hemisphere was covered with numerous, fine, nanoscale nipples with average diameters of (101.1 ± 7.6) nm and interparticle spacings of (47.6 ± 8.5) nm; they organize in an approximately hexagonal non-close-packed (ncp) array. The combination of hexagonally ncp nipples at the nanoscale and hcp ommatidia plays a crucial role in creating the ideal superhydrophobicity for preventing microscale fog drops (moisture) from condensing on the eye surface.

3. Icephobic Biological Surfaces

Wang *et al.* (2016) have reported that feathers of penguins Spheniscus humboldti show hydrophobicity (water CA ≈ 147°) and anti-adhesion characteristics (water adhesive force ≈ 23.4 µN), even for supercooled water microdroplets due to air-infused microscale and nanoscale rough structures. The body feature has combined of different type of micro-nanostructure, in which two pinnae separated by the rachis and barbs are arranged in parallel along the rachis (length and the diameter of the barbs are 5−7 mm and 25−30 µm, respectively). On the tips of the barbs, there are few hamuli with a diameter of ~3 µm and a spacing of ~20 µm between each adjacent hamuli. Penguins live in very cold environment (temperature less than 10°C or even lower) (**Fig. 2**). There is low adhesion force between the barbule surfaces and the supercooled water microdroplets, the feathers exhibits excellent icephobicity in low temperature environment.

In nature, lotus leaf inspired the researchers to artificially fabricate the superhdrophobic surface and pitcher plant inspired to prepare lubricant-infused "slippery" surfaces for ice repellency (Bohn, *et al.* 2004, Zhang, J., Zhang, J., *et. al.*. 2014). The peristome of Nepenthes species has a highly regular microstructure and composed of first- and second-order radial ridges. Microscopic roughness of peristome surface shows hydrophilic wetting state. The plant's produce viscoelastic biopolymers which utilized as a repellent surface to cause the prey to slip into a digestive fluid.

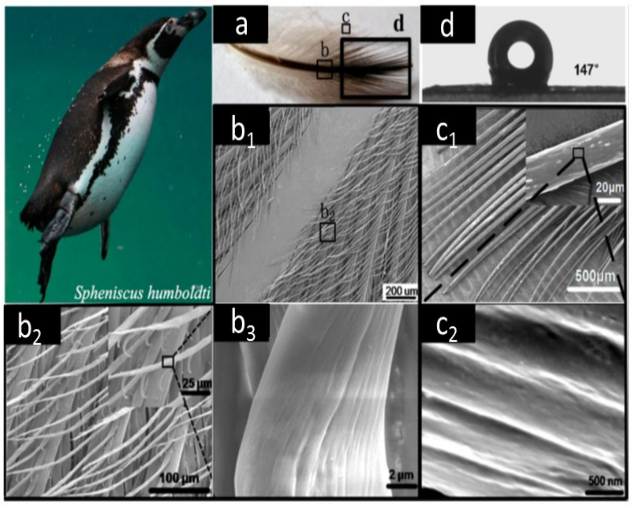

Fig. 2: Different magnified SEM images of body feathers of penguins Spheniscus humboldti. Images reprinted from (Wang, S., *et al.* 2016), with permission from American Chemical Society, Copyright 2016.

CONCLUSION

We reviewed the surface structures of biological surfaces which are building blocks of superhydrophobic and icephobic properties. Lotus leaf and penguin feather has hierarchical micro- and nanostructured surface, which repel water and ice, respectively. These type of surface have potential applications in industry and daily life.

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REFERENCES

Wenzel RN (1936) Resistance of solid surfaces to wetting by water. Industrial & Engineering Chemistry,. 28(8): p. 988-994.

Cassie A and S Baxter (1944) Wettability of porous surfaces. Transactions of the Faraday society,. 40: p. 546-551.

Barthlott W and Neinhuis C (1997) Purity of the sacred lotus, or escape from contamination in biological surfaces. Planta. 202(1): p. 1-8.

Darmanin T and Guittard F (2015) Superhydrophobic and superoleophobic properties in nature. Materials Today,. 18(5): p. 273-285.

Koch K, Bhushan B and Barthlott W (2009) Multifunctional surface structures of plants: an inspiration for biomimetics. *Progress in Materials Science*,. 54(2): p. 137-178.

Feng L *et al.* (2002)Super-hydrophobic surfaces: from natural to artificial. *Advanced materials*, 14(24): p. 1857-1860.

Bhushan B and Her EK (2010) Fabrication of superhydrophobic surfaces with high and low adhesion inspired from rose petal. *Langmuir*, 26(11): p. 8207-8217.

Feng L *et al.* (2008)Petal effect: a superhydrophobic state with high adhesive force. Langmuir,. 24(8): p. 4114-4119.

Rao AV *et al.* (2011) Wetting behavior of high energy electron irradiated porous superhydrophobic silica films. Applied Surface Science, 257(7): p. 3027-3032.

Potyrailo RA *et al.* (2007).Morpho butterfly wing scales demonstrate highly selective vapour response. Nature Photonics, 1(2): p. 123-128.

Vukusic P and Sambles JR (2003) Photonic structures in biology. Nature, 424(6950): p. 852-855.

Zheng Y, Gao X and Jiang L (2007) Directional adhesion of superhydrophobic butterfly wings. Soft Matter, 3(2): p. 178-182.

Goodwyn PP *et al.* (2009) Waterproof and translucent wings at the same time: problems and solutions in butterflies. Naturwissenschaften, 96(7): p. 781-787.

Hansen WR and Autumn K (2005) Evidence for self-cleaning in gecko setae. Proceedings of the National Academy of Sciences of the United States of America, 102(2): p. 385-389.

Liu K *et al.* (2012) Superhydrophobic gecko feet with high adhesive forces towards water and their bio-inspired materials. Nanoscale, 4(3): p. 768-772.

Cai Y *et al.* (2014) Filefish-Inspired Surface Design for Anisotropic Underwater Oleophobicity. Advanced Functional Materials, 24(6): p. 809-816.

Gao X *et al.* (2007) The dry-style antifogging properties of mosquito compound eyes and artificial analogues prepared by soft lithography. Advanced Materials,. 19(17): p. 2213-2217.

Wang S *et al.* (2016) Icephobicity of Penguins Spheniscus Humboldti and an Artificial Replica of Penguin Feather with Air-Infused Hierarchical Rough Structures. The Journal of Physical Chemistry C,. 120(29): p. 15923-15929.

Bohn HF. and Federle W (2004) Insect aquaplaning: Nepenthes pitcher plants capture prey with the peristome, a fully wettable water-lubricated anisotropic surface. *Proceedings of the National Academy of Sciences of the United States of America*, 101(39): p. 14138-14143.

Zhang J *et al.* (2014). Evaporation-induced transition from Nepenthes pitcher-inspired slippery surfaces to lotus leaf-inspired superoleophobic surfaces. Langmuir, 30(47): p. 14292-14299.