Bio Focus

Slippery liquid-infused porous surface coating on steel resists biofouling

Modification of durable materials such as steel to resist biofouling and corrosion in marine and medical applications has been notoriously difficult. Recently, a team led by Joanna Aizenberg of Harvard University and including Philseok Kim of SLIPS Technologies, Inc. has developed a method for coating steel with a slippery liquid-infused porous surface (SLIPS) that is both durable and exceedingly resistant to fouling. The group grew tungsten oxide nanostructures upon the steel, subsequently chemically functionalizing and infusing the pores with lubricating liquid, according to the report published in a recent issue of *Nature Communications* (DOI:10.1038/ncomms9649).

"SLIPS consists of a structured solid that captures a lubricant (which could be water, oil, or another liquid) to create a slippery interface," according to Aizenberg. The "slipperiness" arises because the solid surface is coated with an extremely smooth liquid layer, preventing adhesion to the protected solid. Moreover, these surfaces prevent the penetration of chemicals and are therefore resistant to corrosive agents. Because of the surface structure (porosity), strong capillary forces hold the lubricant layer in place. The group drew inspiration from the carnivorous pitcher plant, whose structured surface becomes slippery when hydrated, capturing insects by hydroplaning them into a deadly trap and preventing them from crawling out.

The present designs necessitate fabrication of robust porous coatings on metal surfaces. Steel is particularly important in that it is used extensively in medical and marine applications where contamination and biofouling are both widespread and especially detrimental. Increasing porosity of materials surfaces generally reduces their durability, so in order to avoid this, tungsten oxide (TO), known for its strength as well as for its good adhesion to steel, was used as the porous layer (Figure a). Researchers applied a fluorinated phosphate treatment to improve compatibility between the fluorinated lubricant and TO. Importantly, the lubricating liquid is nontoxic, and there are US Food and Drug Administration approved formulations.

TO-SLIPS surfaces resisted blood staining as well as bacterial adhesion (*E. coli)* and algae buildup (*C. reinhardtii*), but not through toxic effects. Bacterial and algal biofilms could grow upon horizontally oriented, static surfaces; however, as soon as a shear force was applied by agitation or gravitationally, by tilting the film, the organic matter slid off due to extremely poor adhesion to the surface.

Moreover, these surfaces performed significantly better than structured TO surfaces that were superhydrophobic (TO-SHS), but were not infused with the liquid lubricating layer (Figure b). This is because porous superhydrophobic surfaces resist wetting by entrapping air pockets, minimizing contact area between water (or other applied liquid) and the solid. However, once water displaces these air pockets, the surface can wet. "Then the jig is up," notes Kim, as "bacteria probe and eventually penetrate this aqueous layer, locking themselves into the crevices of the textured substrate." In contrast, "in the case of SLIPS," Aizenberg explains, "the solid is shielded and protected. On a moving, liquid-coated—or on a very soft—substrate, bacteria cannot attach."

Many applications could benefit from this type of technology: "Medical tools such as needles and scalpels need to be durable, while resisting fouling by blood or bacteria," Aizenberg says. Moreover, Kim's company is working to apply durable SLIPS coatings to other metals such as titanium, copper, and particularly aluminum, which could be used for anti-icing refrigerator coils. This new class of multifunctional coatings that are both mechanically durable and antifouling is a triumph for bioinspired materials research.

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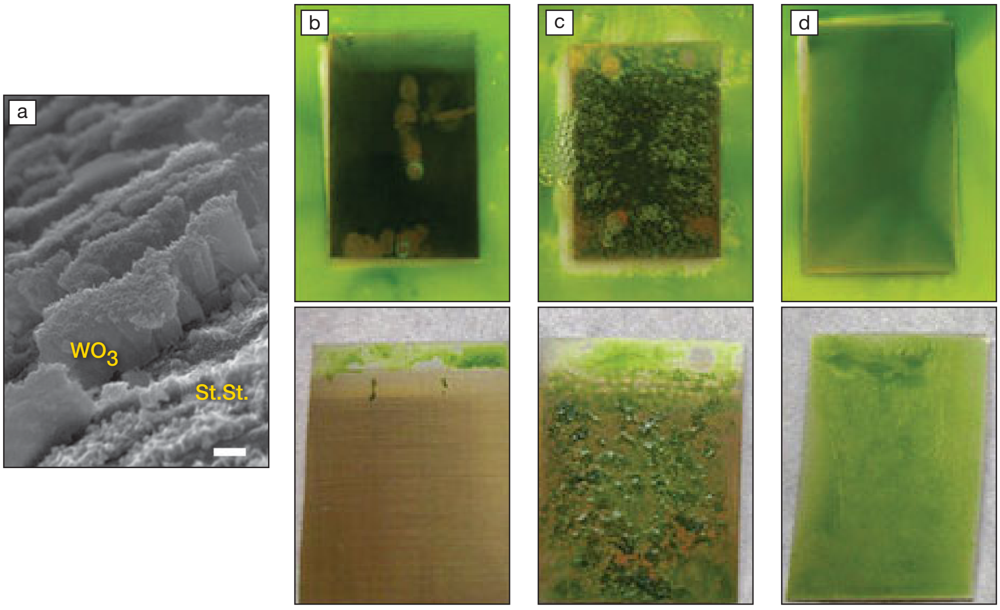

(a) Scanning electron microscope image of a porous tungsten oxide (TO) layer grown on a stainless steel (St.St.) substrate. Scale bar = 200 nm. (b–d) St.St. sample with algae biofilms. Under static culture, algae grows on all the samples (top row); however, when removed from culture and dried (bottom row), the algae film (b) detaches from the TO-slippery liquid-infused porous surface, (c) partially detaches from the TO-superhydrophobic surface, and (d) does not detach from the untreated St.St. control. Credit: *Nature Communications*.

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