# INSIGHTS

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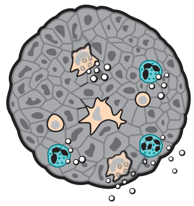
Looking to the past for clues to future climate *p. 151*




**On a roll.** Droplets roll off a superhydrophobic surface.

SURFACE WEAR

# *Moving superhydrophobic surfaces toward real-world applications*

Standardized wear and durability testing is needed to advance the best materials

*By* **Xuelin Tian, Tuukka Verho, Robin H. A. Ras**

Superhydrophobic surfaces have received rapidly increasing research interest since the late 1990s because of their tremendous application potential in areas such as self-cleaning and anti-icing surfaces, drag reduction, and enhanced heat transfer (*1*–*3*). A surface is considered superhydrophobic if a water droplet beads up (with contact angles >150°), and moreover, if the droplet can slide away from the surface readily (i.e., it has small contact angle hysteresis). Two essential features are generally required for superhydrophobicity: a micro- or nanostructured surface texture and a nonpolar surface chemistry, to help trap a thin air layer that reduces attractive interactions between the solid surface and the liquid (*4*, *5*). However, such surface textures are highly susceptible to mechanical wear, and abrasion may also alter surface

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*Published by AAAS*

chemistry. Both processes can lead to loss of liquid repellency, which makes mechanical durability a central concern for practical applications (*6*, *7*). Identifying the most promising avenues to mechanically robust superhydrophobic materials calls for standardized characterization methods.

A variety of methods have been used to test the durability of superhydrophobic surfaces, including linear abrasion, circular abrasion, tape peeling, blade scratching, sand abrasion, ball-on-disk sliding, oscillating steel ball, and water jet tests (*6*–*9*). Although many groups report superhydrophobic surfaces resistant to a certain test, the lack of standardization usually makes comparison of different reported results impossible. An additional issue is that surface wetting is often not characterized in the most useful manner.

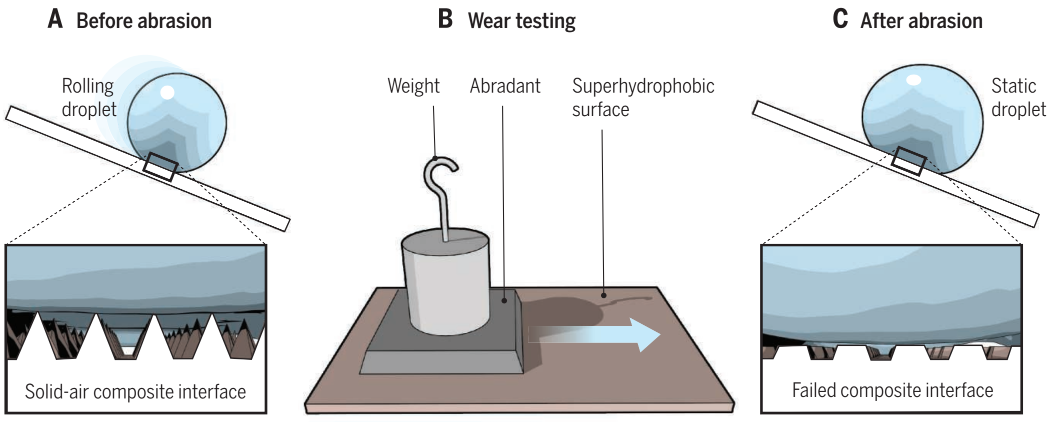
For standardization purposes, a wear-test method should be accessible to most research groups, relevant to most applications, reproducible (that is, insensitive to uncontrolled parameters), and produce a uniformly abraded surface large enough for wetting characterization. The linear abrasion test appears to best fulfill these requirements (see the figure). It involves rubbing a flat solid abradant against the sample surface under a normal load (*7*, *10*, *11*).

Although linear abrasion is already often used for testing the mechanical durability of superhydrophobic surfaces, many studies do not specify sufficient details to facilitate comparison among different materials. The applied normal pressure obviously needs to be controlled. Also, a key parameter is the abrasion distance experienced by each point on the abraded surface, which is the product of the number of abrasion strokes and either the stroke length or the length of the abradant head (whichever is smaller). A problem may arise if the abradant head is circular instead of rectangular, as the abrasion distance may then not be uniform over the abraded area. Whether the abradant moves and the sample stays stationary, or vice versa, is a matter of choice. The effect of abrasion speed may need investigation, but is not expected to be critical.

A difficult matter is the choice of abradant. In applications, a superhydrophobic surface may be exposed to rubbing of materials with varying hardness, texture, and resilience. Milionis *et al.* suggested testing a large combination of properties with a set of three materials—textile, rubber, and vitrified (sandpaper) abradants (*7*). Such a test series is reproducible between research groups only when the precise type of each abradant is well defined; for this, commercial standardized abradants might present a solution. However, hard abradants usually cause the strongest wear action, so a simple but satisfactory option that would enable community-wide comparison could be the use of silicon carbide sandpapers. Such sandpapers are available with grit size ranging from coarse to ultrafine, allowing determination of the wear response to hard textures with either roughening or smoothening effect.

Even a well-conducted wear test is of little value without characterization in terms of droplet mobility and the advancing and receding contact angles (contact angles to initiate the advancing and receding of a solid-liquid contact line, respectively). Reporting only static contact angles (contact angle after droplet deposition) is common but unfortunately of little value. The static contact angle is not easily affected by abrasion because the advancing contact angle stays high. However, the receding contact angle of abraded surfaces is often quickly reduced, which leads to large hysteresis (difference between the two contact angles) and low droplet mobility (*4*). It is imperative to characterize the effect of wear in terms of change in contact angle hysteresis or just in the receding contact angle. Alternatively, the sliding or roll-off angle can be used (critical surface inclination at which a sessile droplet starts to move), as it is related to contact angle hysteresis (*12*). In this case, the droplet volume affects the sliding angle (*5*) and needs to be reported. Prior to wetting characterization, the surface should be cleaned of debris.

Numerous opportunities are emerging from the study of superhydrophobic materials, so standardized wear testing is highly desirable to accelerate their transfer to real applications. We suggest that linear abrasion should be a primary test and that pressure, abrasion distance, and abradant materials should be clearly specified. The wear-induced change in contact angle hysteresis, receding contact angle, and/or sliding angle should be given. The wear intensity should be incremented up to the point of failure, instead of performing a cursory test and declaring the surface wear-resistant. Although the linear abrasion test is recommended for all superhydrophobic surfaces, additional tests are encouraged—for example, a substrate adhesion test for superhydrophobic coatings (*13*), a laundering test for superhydrophobic textiles (*14*), and a water jet test for outdoor (rain) applications. ■




**Wearing out a nonwetting surface.** A superhydrophobic surface generally loses its liquid repellency after mechanical abrasion. (**A**) A water droplet rolls on a superhydrophobic surface, where the liquid is suspended by a solid-air composite interface. (**B**) A setup for linear abrasion test. (**C**) A droplet gets stuck on the same surface after abrasion because of the failure of the composite interface.

ILLUSTRATION: C. BICKEL/*SCIENCE*

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### ACKNOWLEDGMENTS


Supported by the Academy of Finland through its Centres of Excellence Programme (2014–2019) and under project nos. 263560 and 283210. We thank J. Li for help in the figure preparation and M. Latikka for taking the photograph.

10.1126/science.aaf2073

Science
AAAS

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*Science* **352**, 142 (2016);
DOI: 10.1126/science.aaf2073