Superhydrophobic and Omniphobic materials for self-cleaning soldiers clothes and reduce fuel costs of Ships and Submarines

Normal solid surfaces are wetted by liquids such as water and oil. In many cases, surface wetting is undesirable due to the fact that the liquids may largely deteriorate the functionality of the surface, or cause unwanted effects. For example, evaporation of liquid droplets could leave behind chemical or dirt residue on the surface; soot and oily deposits may contaminate the surfaces and they are normally hard to remove without scrubbing.

The utility of omniphobic surfaces stems from their ability to repel a multitude of liquids, possessing a broad range of surface tensions and polarities, by causing them to bead up and either roll or slide off. These surfaces may be self-cleaning, corrosion-resistant, heat-transfer enhancing, stain-resistant or resistant to mineral- or biofouling. The majority of reported omniphobic surfaces use texture, lubricants, and/or grafted monolayers to engender these repellent properties.

Under certain conditions, military coatings can become soiled or contaminated by oil or water borne chemical agents, or oily matters from engine exhaust. Surface coatings that are durable and self-cleaning are desirable. This kind of coating has to be both hydrophobic and oleophobic so that contaminants won’t adhere to the coating surfaces and will come off easily.

“On the battlefield, the soldiers don’t have field laundering equipment. In the event they get clothing dirty…they can just stand up and eventually the dirt will just fall off and the uniform is clean again,” says Truong.

The US Navy’s Office of Naval Research (ONR) is sponsoring the development of a new type of ‘omniphobic’ ship coating that is intended to help reduce fuel and energy costs. The U.S. Navy wants a slick new material that can shed any liquid or semi-liquid that comes into contact with it. When applied as a coating to the hulls of ships and submarines, the “omniphobic” material will immensely reduce friction drag, allowing the sea-going craft to travel faster without using as much energy or fuel, an article in Science Daily reported.

Superhydrophobic and Omniphobic materials

Superhydrophobic materials can be made in several ways – by coating a surface with a superhydrophobic material, by nanostructuring a surface, by applying nanoparticles to a surface or by a combination of these. Superhydrophobic coatings are very low surface energy coatings such as special waxes.

In the case of a liquid resting on a solid surface in a gaseous environment, the contact angle can be defined as the angle formed by the liquid at the gas, liquid, solid boundary. Due to the high surface tension of water, it tends to form spherical droplets on surfaces, so as to reduce its area and thus energy. The contact angle is therefore generally large, although this depends on the surface material.

Microstructuring a surface – in other words adding in unevenness or asperities – amplifies the natural tendency of the surface. Therefore, for hydrophilic surfaces, the contact angle will decrease while for hydrophobic surfaces, the angle will increase. If the angle is greater than 150°, the material is classed as superhydrophobic. If the liquid particle is resting on top of the asperities then the increase in angle is greater than if the liquid is still in intimate contact with the original surface of the solid. A hierarchical structure in which the microscale asperities themselves have nanoscale roughness is found to give better superhydrophobic properties.

Two excellent examples of natural superhydrophobic materials are the lotus leaf and the gecko foot. In fact, the superhydrophobic property is sometimes referred to as the lotus effect. The leaves of the lotus consist of micro- and nano-scale papillae that are coated in a hydrophobic wax. This double structure makes the leaves superhydrophobic and water makes a contact angle of up to 170°.

Challenges in developing these materials:

1. It is difficult to select the functional materials that possess both hydrophobicity and oleophobicity. The surface tensions of oils (including organic solvents) are smaller than water, so a surface that repels water is not necessarily oil repellent. However, an oil repelling surface has to be water repelling in the first place, and
2. It is challenging to properly incorporate oleophobic materials into a coating resin system and make the

coating mechanically durable, due to a lack of functional groups on oleophobic particles for chemical bonding.

Many attempts have been made by researchers to produce oleophobic surfaces on a variety of solid substrates in the past decade. Shibuichi etc prepared a super oil-repellent surface using anodically oxidized aluminum surface treated with fluorinated monoalkyl phosphates. The contact angle of rapeseed oil on this surface reached 150º. Yabu etc formed hydrophobic and lipophobic surfaces of fluorinated polymers by a water-assisted self-assembling process which produced a honey-comb-patterned film. Li etc treated ACNT (aligned carbon nanotube) films formed on quartz surface by using hydrolyzed heptadecafluorodecyltrimethoxysilane. The fabricated surfaces showed “amphiphobic” properties.

Many other researchers have reported their amphiphobic surfaces as well. All the above reported research employed fluorinated polymers as the top surface, or fluorinated organic agents to treat the top surface. Use of fluoro-containing materials to produce oleophobic surfaces is a “must” approach concluded by many of the abovementioned researchers. Furthermore, all of the current arts in producing super amphiphobic surfaces require rough base surfaces, which is another “must” for higher oil contact angles.

For some applications, having a hydrophobic coating is sufficient, but in certain situations it is desirable to have a material whose bulk is hydrophobic. Scientists at MIT have manufactured ceramic samples that are intrinsically hydrophobic and therefore can withstand extreme environments, such as those in a furnace, while displaying hydrophobic properties. The materials employed are powdered oxides of rare earth metals and display hydrophobic properties even after they are damaged, for example by abrasion. The MIT team has also coated a nanostructured material with the ceramics to form durable superhydrophobic surfaces from which water was observed to bounce off.

MIT Finally Develops a Surface Design that Repels Virtually Any Liquid

A team of researchers at MIT are using nanotechnology to solve an old dilemma that has stumped many scientists: how to design a surface that is consistently liquid repelling in every type of condition.

The team's work was a true collaboration, made possible by generous support from the Abu Dhabi National Oil Company, the Air Force Office of Scientific Research, the Office of Naval Research, the Masdar Institute of Science and Technology in Abu Dhabi (now under the name of Khalifa University) and the National Science Foundation, all of which formed an agreement with MIT to encourage the research.

The study involved taking a fresh approach toward omniphobic surfaces, which as the name implies, refers to a type of surface which can "reject" all types of liquids. Although this is by no means the first time that omniphobic surfaces have been considered as a viable option in achieving liquid-repelling results, the problem of condensation always remained, a frustrating challenge which the researchers described as a "phenomenon ubiquitous in both nature and industrial applications”.

To successfully produce these results, the team strictly controlled the (1) temperature and (2) scale of the materials. The surface was able to repel liquids up to 10 °C below the dew point, with results lasting over a 3-week period. In terms of the reentrant cavities, or ridges, through which the liquid would pass, a 100 nm size was chosen, which stopped the two processes of nucleating AND dispersing from occurring.

The process of making the ridges involved a number of steps including carving out the ridges, coating their edges, and then carving out a space within the new coatings: the result was an iron-clad surface.

MIT Mechanical Engineering Professor Kyle Wilke describes how the team created a very delicate process in order to overcome the hurdle of condensation: “Many liquids are perfectly wetting, meaning the liquid completely spreads out. Those are very difficult to repel. The only way to do it is through very specific surface geometry, which is not that easy to make.

The team’s research suggests that by refining the process of creating robust surface-repellant surfaces, that many in the industry will begin to reconsider the merits of omniphobic surfaces. The range of applications covers various refrigerants as well as hydrocarbons which can be used in the form of lubricants, fuels and alcohols. “We wanted a structure that one defect wouldn’t destroy,” he adds.

Omniphobic coating can allow ships to go faster through water

University of Michigan associate professor of materials science and engineering Dr Anish Tuteja is being sponsored by ONR to develop the omniphobic coating. U.S. Navy wants to create a new type of “omniphobic” coating, a material that is clear, durable, can repel water and reduce friction drag.

The UM-developed omniphobic material promises to solve the problem of friction drag. If applied to the hull of a ship, water will be unable to actually touch it. Instead, the liquid will bead up and slide away from the hull. The coating can help to reduce friction drag, which is the resistance created during the movement of a hull through water on ships, submarines and unmanned underwater vessels.

“A significant percentage of a ship’s fuel consumption [up to 80 percent at lower speeds and 40-50 percent at higher speeds] goes toward maintaining its speed and overcoming friction drag,” explained Ki-Han Kim, a program officer with the Office of Naval Research (ONR) of the U.S. Navy. “If we could find a way to drastically reduce friction drag, vessels would consume less fuel or battery power and enjoy a greater range of operations.”

Repellent coatings are usually specialized to resist only a few types of liquids. Furthermore, it is difficult to create one that will also stick to the surface of an object for a long period of time. Teflon is a good example of the capabilities and limitations of phobic coatings. When water ends up on a Teflon-coated surface, it will bead up and roll off the pan. However, oil will spread across the non-stick surface since it has different properties from water. Teflon can also be scratched off the surface of the pan.

“Researchers may take a very durable polymer matrix and a very repellent filler and mix them,” Tuteja said about omniphobic materials. “But this doesn’t necessarily yield a durable, repellent coating. Different polymers and fillers have different miscibilities.”

Miscibility is the ability of two different substances to combine with each other. Tuteja said that this made the process of creating a composite material much more complicated than just mixing together the most durable ingredients one could find.

New coating is see-through, tough as nails, and repels almost all liquids. Laboratory trials confirmed the potency of the mixture.The new omniphobic coating has the texture of rubber. It can be brushed, dipped, spin-coated, or sprayed onto various surfaces. It binds very firmly with the surface it is applied on. It is also able to resist damage from the kind of rough treatment that comes with everyday use. Last but not least, the coating is transparent.

The omniphobic coating's application is not just limited to waterproofing the hulls of ships and submarines. Tuteja suggested that it can also serve as a weatherproofing coating for delicate, expensive equipment.

Self-Cleaning Clothes Invented By The Military Could Make Laundry A Thing Of The Past

Army physical scientist, Quoc Truong and his team have been working on "self-cleaning clothing" at the U.S. Army Soldier Research, Development, & Engineering Center in Natick, Massachusetts. Truong's dream: clothing that won't get dirty in the first place!

The U.S. Army has about a million soldiers including active duty, reservists and National Guard. Each soldier is issued five uniforms. With the constant wear and tear that uniforms undergo in the field – that's a lot of laundry! Challenged by a general to invent a uniform that didn't need cleaning, Truong examined the molecular level of the fabric and the substances that make it dirty. To make uniforms that actually resist a wide array of water- or oil-based substances, Truong and his team have been working on what he calls an "omniphobic coating."

The tests reveal that everyday substances, like ketchup or chocolate sauce, tend to be repelled or slide off the uniform fabric. The coated uniform fabric can even resist tough substances like motor oil – which beads up on the fabric surface, instead of soaking through. Truong has even figured out a solution for the smell that could come from clothes that don’t get laundered. By adding antimicrobial additives to the coating, stinky odors are no longer an issue.

It’s not just the military that could be using self-cleaning clothes. Commercial manufacturers have been approached about using the omniphobic coating. So someday, both the military and the general public may not have to worry about cleaning clothes again.

References and Resources also include:

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