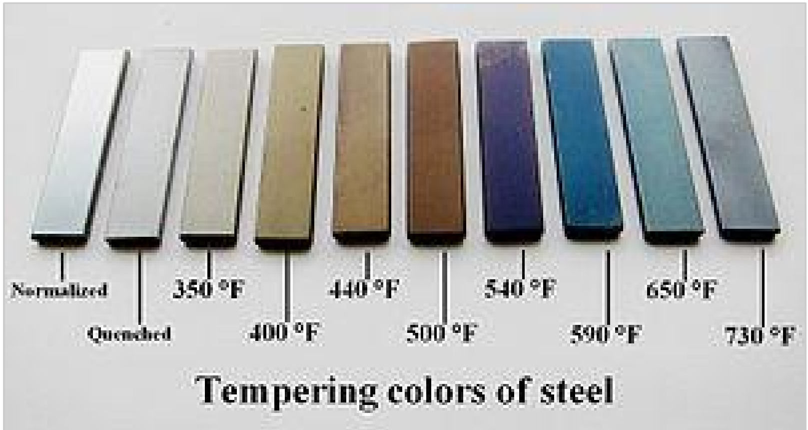
# Nano Activities Explained

### Tempering colors




Pieces of through-tempered steel flatbar. The first one, on the left, is normalized steel. The second is quenched, untempered martensite. The remaining pieces have been tempered in an oven to their corresponding temperature, for an hour each. "Tempering standards" like these are sometimes used by blacksmiths for comparison, ensuring that the work is tempered to the proper color.

If steel has been freshly ground, sanded, or polished, it will form an oxide layer on its surface when heated. As the temperature of the steel is increased, the thickness of the iron oxide will also increase. Although iron oxide is not normally transparent, such thin layers do allow light to pass through, reflecting off both the upper and lower surfaces of the layer. This causes a phenomenon called thin-film interference, which produces colors on the surface. As the thickness of this layer increases with temperature, it causes the colors to change from a very light yellow, to brown, then purple, then blue. These colors appear at very precise temperatures, and provide the blacksmith with a very accurate gauge for measuring the temperature. The various colors, their corresponding temperatures, and some of their uses are:

- Faint-yellow – 176 °C (349 °F) – engravers, razors, scrapers
- Light-straw – 205 °C (401 °F) – rock drills, reamers, metal-cutting saws
- Dark-straw – 226 °C (439 °F) – scribers, planer blades
- Brown – 260 °C (500 °F) – taps, dies, drill bits, hammers, cold chisels
- Purple – 282 °C (540 °F) – surgical tools, punches, stone carving tools

- Dark blue – 310 °C (590 °F) – screwdrivers, wrenches
- Light blue – 337 °C (639 °F) – springs, wood-cutting saws
- Grey-blue – 371 °C (700 °F) and higher – structural steel

Beyond the grey-blue color, the iron oxide loses its transparency, and the temperature can no longer be judged in this way. The layer will also increase in thickness as time passes, which is another reason overheating and immediate cooling is used. Steel in a tempering oven, held at 205 °C (401 °F) for a long time, will begin to turn brown, purple or blue, even though the temperature did not exceed that needed to produce a light-straw color. Oxidizing or carburizing heat sources may also affect the final result. The iron oxide layer, unlike rust, also protects the steel from corrosion through passivation.

## Material of the month: Superhydrophobic materials - surface properties

*By Maria Felice*

**What do the leaves of a lotus plant and the feet of a gecko have in common? Superhydrophobicity. Maria Felice examines the properties and benefits of these materials.**

To understand how hydrophobic materials work, let's begin with a brief explanation of surface tension and contact angle. Cohesion forces hold liquid molecules together, and since the molecules on the surface are not surrounded in all directions by other liquid molecules they need to exert stronger forces on their neighbours. This stronger force at the surface is the surface tension and is what provides the resistance to objects being pressed into the liquid. Surface tension is expressed as a value of force required to break a film of liquid that is 1cm long. The force value is expressed in dynes (dyn) where 1dyne is equal to 10μN. The surface tension values at 20°C for benzene, water and mercury are 29dyn/cm, 73dyn/cm and 487dyn/cm respectively. In the case of solids, the molecules on the surface are also not as strongly bonded as those inside and the resulting energy is referred to as surface energy. The higher the surface energy of a material, the higher its bonding potential with other materials.

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. Due to its high surface tension, water has a high capacity for bonding if the surface is right. Hydrophobic surfaces are ones with a low surface energy that therefore do not attract water to them. For these materials the contact angle is greater than 90°. Hydrophilic surfaces, such as glass, have a high surface energy and water spreads out over them. For these materials the contact angle is less than 90°.

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.

**Nature knows best**

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°. The resulting selfcleaning effect means that lotus leaves are free from dirt and bacteria, despite growing in dirty ponds. Similarly, the way geckos can walk quickly while upside down fascinates lay people and scientists alike. The pads of a gecko's feet are covered with tiny fibres made of the protein keratin. These enable the gecko to adhere strongly to a surface but at the same time allow it to lift its feet quickly so that it can walk along a surface at speed without falling off. If these fibres become dirty, the function would be lost. In recent years, it has been discovered that the gecko secretes an oil that imparts superhydrophobic functionality to keep the toe fibres clean and therefore in good working order.

*Gecko*

The properties of man-made superhydrophobic materials were reported in the 1970s and 1980s, and research has accelerated since the 1990s. 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.

Synthetic surfaces with a micro-nano-binary structure can be created, similar to the structure of lotus leaves. For example, vapour-induced phase separation, which occurs when a polymer is cast in a carefully controlled moist environment, can be used to make superhydrophobic polycarbonate surfaces. Tiny particles can be applied to fabric surfaces to make them superhydrophobic. For example, silica nanoparticles can be applied using the sol-gel technique in which the particles are dispersed into a colloidal solution (sol) and then agglomerate together to form a solid network (gel). And silica nanoparticles can be deposited on already hydrophobic carbon fabric to make it superhydrophobic.

In 2012, a team from the Australian Future Fibres Research and Innovation Centre at Deakin University in Melbourne devised a better way of covering fabrics with a water-repellent and self-cleaning coating. They did this by repeatedly dipping the fabric into a solution of tiny particles of silica. The protective coating was formed using layer-by-layer selfassembly. The team coated the particles with long chemical tails that ended in azido groups (from the azide anion N3-) and found that, as in previous work, the coating was not very durable. However, curing the coating under UV light caused the azido nanoparticles to interlink and resulted in a tougher structure.

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.

Superhydrophobic materials are solving an increasing number of problems and this is thanks in part to the lotus leaf and the gecko foot that inspired scientists and engineers to test some of the limits of material science.

**Definitions -**

**Hydrophobic**: Includes oils and fats. Repels water and is difficult to wet.

**Superhydrophobic**: More efficient than hydrophobic materials thanks in part to nanotechnology. Many coatings applications to keep materials clean, ice-free and sterile. Can also be used to increase the efficiency of watercooling stations, desalination plants and other systems involving condensation, by encouraging the water to drip off the condensing surfaces.

**Hydrophilic**: Includes sugar and salt. These materials like water and their applications include soft, breathable contact lenses that allow gases that are carried in water to pass through.

**Omniphobic**: Dislikes everything. Can repel oil and water.