in these genes among the strains. Various combinations of these altered genes established distinguishable genotypes for each sample. Aa and Townsend demonstrated that the yeast found on grapes were not that similar to the yeast recovered from the wine must in fermentation vats. Instead, yeast from wine vineyards around the world include many wild strains and greater genetic diversity than that of yeast from the must. "The wine yeast does not represent a [global] population of domesticated strains as has been suggested," notes Christian Landry of Harvard University in Cambridge, Massachusetts. The vineyard yeast were also quite different than the yeast recovered from oaks.

Two samples from Italy's Elba Island also hinted that the yeast found on grapes may differ significantly from vineyard to vineyard within a region. Townsend discovered that yeast from the Elba samples resembled mainland strains but also contained genotypes unique to the island. He plans to expand the study to determine whether other places have distinctive yeast populations and, perhaps as a result, distinctive wines.

Two of the four yeast genes studied by Townsend and Aa had telling changes that may explain some of the vineyard-to-vineyard strain variation. One, the *SSU1* gene, is involved in transporting sulfite—a toxin—out of the yeast cell. The second is a gene whose protein regulates *SSU1*'s activity. The more active *SSU1* is, the more resistant the yeast is to this toxin. The *SSU1* regulatory gene showed the greatest number of differences from strain to strain, which translated into slightly different proteins and indicated that it had evolved the fastest of the four genes studied. Viniculture practices could explain this rapid change, says Townsend. In the vineyard, grapes are treated with sulfite and sulfite-containing compounds that destroy mold and other microbes, presumably killing all but those yeast with high *SSU1* activity. Also, winemakers add sulfite to sterilize fermentation vats, again presumably killing all but the most tolerant yeast.

Townsend notes that with such treatments, winemakers end up with ever more useful strains. The more resistant a *S. cerevisiae* strain is to sulfur-based chemicals, the longer the yeast cells will survive in vats treated with sulfite, and the more alcohol they make. "[Wild] wine yeast has inadvertently been domesticated," concludes Townsend. That's worth a celebratory drink.

–ELIZABETH PENNISI

Nanomaterials

'Smart Coatings' Research Shows The Virtues of Superficiality

Thin, shallow, and out to strike it rich—high-tech protective paints and varnishes look poised to become the first "killer apps" for nanotechnology

BERLIN—Clothing with computers woven into the fabric. Microscopic robots that make repairs with tools the size of a virus. No question about it: Nanotechnology, the applied science of the very small, has generated its share of megahype. For companies researching nanomaterials, however, profitability is the priority—and not in the dreamy future but now. Many are concluding that the beauty of the technology is literally skin deep.

Hot and heavy. This Fraunhofer Institute test furnace measures how much weight treated wood can bear after burning.

CREDIT: FRAUNHOFER INSTITUTE

At a recent meeting here,* researchers from around the world swapped news about efforts to spin nanotech into products based on surfaces with novel properties. "Coatings applications are among the first true everyday uses of nanotechnology," says Dirk Meine, a chemist who organized the conference for Vincentz Network, a coatings industry media group. Examples include nanoparticle-laden varnishes that combine the scratch resistance of an inorganic crystal with the versatility of an organic plastic. (Super–scratch-resistant coatings are already on the market.) Researchers offered a glimpse of what may be the next wave of nano applications to enter daily life.

* Fourth Annual Smart Coatings Conference, 9–10 June.

Combating corrosion

The biggest task in the coatings industry is to slow down corrosion. Pipes rust, bricks crumble, and timbers rot, calling for repairs that add up to 4% of the gross national product of Western countries, according to Ubbo Gramberg, a corrosion chemist at Bayer in Leverkusen, Germany. "Not all these corrosion problems can be solved by coatings, but a considerable percentage can," says Michael Rohwerder, a physicist at the Max Planck Institute for Iron Research in Düsseldorf, Germany.

Top prize will go to a coating that prevents the corrosion of steel. Today, even the best protective coatings allow oxygen to diffuse slowly through to the metal surface. Corrosion kicks into overdrive when coatings begin to peel off, a process called delamination.

The trouble starts at microscopic nicks or pits on the surface introduced during manufacturing or through wear and tear. These defects form miniature circuits in which electrons flow through the metal in one direction while positive ions such as sodium flow back along the metal surface, leaving a degraded metal-coating interface in their wake. The coating becomes separated from the metal and flakes away, exposing fresh metal and accelerating the process.

That is where nanotechnology could come to the rescue. Rohwerder's group is working on coatings that allow a corroding metal surface to "self-heal." The oxidative attack at the site of a defect triggers nanoparticles to release corrosion-inhibiting ions—in this case, negatively charged molybdate ions—that stand in for the metal and form a protective oxide skin. Once the defect is sealed, the coating stops releasing ions until the next attack.

But there's a catch. Because these coatings sense corrosion with innately conductive polymers (ICPs)—carbon chains that allow charge to flow along their length like the semiconductors in microchips—they actually pro-

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mote corrosion except under controlled conditions. Designing "smart" ICP coatings that remain protective in unpredictable environments requires a "balancing act," says Sze Yang, a chemical engineer at the University of Rhode Island in Kingston. Another problem is that most ICPs are difficult to work into standard coating solutions, a drawback that could make them a commercial nonstarter despite their excellent anticorrosion properties.

Yang says he and colleagues have discovered an elegant solution to some of these problems. They found that synthesizing an ICP called polyaniline into a DNA-like double helix makes it far less corrosion-prone. The helix form is also easier to integrate into several coating mixtures. The researchers hope to find a replacement for chromates, the nearly universal additive to metal coatings that protects against corrosion but is a potent toxin, causing environmental havoc when it leeches out. It's too soon to say whether the badly needed successor to chromate will be Yang's double-helix ICP, but most coating experts agree that whatever it is, it will likely come from nanotechnology.

Fighting fire with nanoparticles

Nanomaterials may also help hold at bay rust's dramatic cousin, fire. Flame-retardant coatings have been widely used since the 1970s, but they have a serious drawback. According to Stefan Sepeur, a chemist at technology company Nano-X in Saarbrücken, Germany, more than 90% of fire-related deaths "are not caused by the flames but by the emission of toxic and corrosive gases"—many of which come from the fire-retardant coatings themselves. So finding alternatives for these formulas, which include toxic epoxy and acrylates, would save lives.

At Inomat, a coating research company in Bexbach, Germany, engineers have developed a way of coating surfaces with nanoparticles of flame-retardant oxides of aluminum or silicon. Because the particles are so small, they can be incorporated into a water-based solution, sidestepping the toxic organic compounds that make up standard formulas. One problem still to be overcome is that it requires a temperature of 100°C during application, limiting its use to steel and aluminum rather than the inside walls of houses where it is most needed.

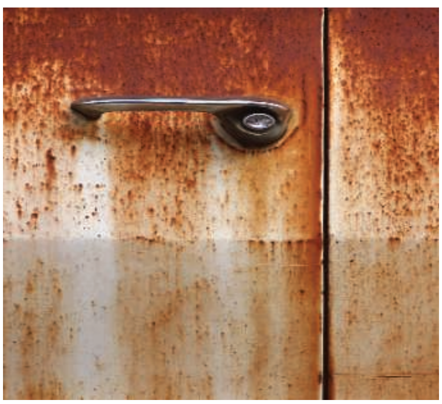
In a very different approach, researchers at the Fraunhofer Institute for Wood Research in Braunschweig, Germany, are trying to endow surfaces with their own fire extinguishers. What looks and behaves like a normal paint or varnish at room temperature suddenly erupts in a layer of carbon foam in the presence of flame. The foam, composed of so-called ceramizing elastomers, was developed 35 years ago to insulate the combustion chambers of rockets, says Sebastian Simon, a chemical engineer on the project. The first challenge, he says, was to engineer the unexpanded polymers into a heat-sensitive coating that could pass muster as a household varnish. To test it, Simon and colleagues coated a wooden staircase and roasted it at 900°C for half an hour. Each stair could still bear a 100-kilogram weight after the ordeal.

Where there's smoke. Toxic fumes from fire-retardant coatings can be as deadly as flames.

War and peace

Other researchers are pitting smart coatings against even worse worst-case scenarios. At the University of Pittsburgh, Pennsylvania, molecular biologists Richard Koepsel and Alan Russell are working on a coating that protects against attacks with biological or chemical weapons. With funding from the U.S. military, they are developing a "bioreactive plastic" embedded with antibodies and enzymes that decontaminate surfaces as soon as pathogens or toxins arrive.

The biological principles are simple, Koepsel says. The coating contains enzymes for breaking down various poisons into harmless smaller molecules. And for each of the prime pathogenic suspects, such as anthrax or smallpox, a specific antibody lies in wait to grab it with enzymes such as cell-popping lysozymes nearby.



Handle with care. Nanomaterials may someday replace toxic rustproofing compounds.

One problem is that all these proteins evolved to function in the wet, salty environment within organisms, not outdoors. But after much tinkering, Koepsel and Russell found mixtures of water-retaining materials such as polyurethane in which enzymes remain 60% active after more than 20 weeks. Other chemical tricks helped keep the proteins at the outermost surface of the coating where the action is, instead of trapped and useless within the interior.

Koepsel says the coating has done well against simulated attacks of *E. coli* bacteria and harmless molecules, and the same principles should apply for the real deal. A self-decontaminating surface alone, he acknowledges, won't keep people inside a building or vehicle perfectly safe. But it should provide at least "a moderate level of protection for occupants of unsealed buildings and vehicles" and could make it easier to clean up after an attack. He says he is also pondering ways to equip the coating with an alarm system to alert people that an invisible attack is taking place.

Antimicrobial coatings could also soon find niches in operating rooms and in medical devices such as catheters that must remain inside the body for days at a time. When it comes to fighting infection, "nano is a natural given the size of bacteria," says Alexander Klibanov, a materials scientist at the Massachusetts Institute of Technology in Cambridge. The main obstacle right now, Klibanov says, is that antibacterial nanocoatings are expensive. He expects that the coatings won't make it onto the consumer market until they've been adopted by the "price-insensitive" hospital and homeland security areas. But once they have become cheap and proven effective, he predicts, they're bound to become as common as a coat of paint.

–JOHN BOHANNON

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